THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

FEBRUARY, 1958

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Microstructures of Cast Metals: Handbook

INST. BRIT. FOUNDRYMEN: 'Typical Microstructures of Cast Metals.'

Published by the Institute, July 1957; 224 pp. Price : Members £1 1s. 0d; Non-Members £4 4s. 0d.

This Handbook has been prepared by three Sub-Committees of the Technical Council of the Institute. It is an amplified successor to Series I and II of 'Typical Microstructures of Cast Iron', published by the Institute in 1935 and 1936.

The new 'Atlas' comprises the most comprehensive collection of microstructural data ever published. The annotations accompanying the photomicrographs, together with an introductory chapter on photomicrographic technique, bring together a mass of valuable information which has never before been assembled in one volume. The reference nature of the contents precludes detailed mention in abstracting, but in order to demonstrate the wide range of information available in the original, a skeleton note on contents is given below.

Extract from Preface: 'The new collection of photomicrographs includes not only the well-established foundry alloys (ferrous and non-ferrous) but also covers the more recent developments in cast irons, and microstructures of steel and non-ferrous castings.

'As a basis for compilation, British Standards are used where convenient, but as the purpose is to present comprehensive examples of the metals and alloys used in commercial casting production, many illustrations are included for which there is no relevant British Standard, and additional photomicrographs are introduced where necessary to show specific structures.'

An opening chapter, dealing with *Preparation of Specimens for Microscopic Examination*, includes sections on sampling, mounting of specimens, grinding, abrasive smoothing, polishing (by mechanical and electrolytic methods), and etching. In the etching section, typical reagents and procedures are given for preparation of steels and cast irons, and for non-ferrous alloys of aluminium-, magnesium-, copper-, and nickel-base types.

The main volume is divided into sections containing microstructures typical of the following groups of casting materials, and of specialized structures which may occur in several types of material. The range of coverage is indicated by the list in the right-hand column.

Cast Irons (of all types, in as-cast and heat-treated conditions, including surface-hardened types)
Steels (ranging from low-carbon to highly-alloyed heat- and corrosion-resisting materials)
Copper-base alloys typical of those in current use (This section includes illustrations of defects likely to occur in such alloys)
Aluminium-base alloys (including illustrations of inclusions apt to occur in these alloys, and micrographs demonstrating the influence of pouring temperature on grain size)
Magnesium-base alloys
Nickel-copper alloys
Zinc-base alloys for die castings
Lead- and tin-base alloys

Recent Progress in Production of Cast Components

See abstract on p. 47.

Brittle Fracture of Metals: Monograph

C. F. TIPPER: 'The Brittle Fracture of Metals at Atmospheric and Sub-Zero Temperatures.'

Metallurgical Reviews, 1957, vol. 2, No. 7, pp. 195–261.

This monograph, documented by a *bibliography* of 247 references, and amply illustrated, gives a survey of present knowledge on the theory of brittle fracture, the mechanism by which it occurs, the factors influencing susceptibility to such fracture, and tests used for estimation of brittleness. The comprehensive nature of the review may be gauged from the outline of contents given below.

The Concept of Brittleness
Fracture of Metal Crystals (by cleavage, or shear)
Fracture of Polycrystalline Aggregates
(Transcrystalline and intercrystalline fracture; the importance of grain size)
Development of Patterns on Fracture Surfaces
Effect of a Notch
(Stress concentration; complicated stress distribution; plastic constraint)
Effect of High Rates of Loading
„ „ Pre-strain on Fracture
Fatigue Fracture
Ludwik's Theory of Fracture and Notch Brittleness
Assessment of Brittleness by means of Mechanical Tests
(General comments on test methods; criteria adopted for failure in various tests; influence of notch acuity; effect of machining of notch on test results; necessity for temperature control in testing; static *vs.* dynamic tests; scatter in test results)
Types of Notch-Bar Test
(Notch-tensile; bend; tensile-bend; Pellini drop-weight; Pellini 'bulge'; Robertson and S.O.D. tests)
Metallurgical Factors affecting Fracture in Steels
(Methods which have been adopted for study of this aspect; effect of individual elements (C, Mn, Si, S, P, O, N, H, Ni, Al, Cr, Mo, V, Ti, Cu, Co, B, rare-earth metals); steel-making practice; strain-

ageing and quench-ageing; directional properties in rolled sections)
Metallurgical Factors affecting Fracture in Non-Ferrous Metals
(Molybdenum; chromium; other alloys showing ductile-to-brittle transition)
Service Failures due to Low-Temperature Brittleness
Initiation and Propagation of Fracture

Survey of the subject under the above headings leads the author to the following conclusions:

'From the practical point of view, the most important question to answer is why fracture by cleavage occurs instead of plastic yield. This review of conditions favouring cleavage fracture has shown that low temperature is the most critical in those substances which are liable to cleavage. Probably next in importance is high rate of application of load, and attention has been directed to the close relation existing between low temperature and high strain rates. These and other conditions which raise the yield point by preventing shear support the view that a high yield stress may be an indication of a tendency to brittleness, but this conclusion is contrary to evidence. Little value can also be attached to any determination of cleavage strength or fracture stress.

'The most valuable property a metal can possess is ductility: ability to deform sufficiently between yield and ultimate stress, in order that stress concentrations may be smoothed out, accompanied by ability to deform under localized, multiaxial stresses such as arise during neck formation when fracture begins. Unless the second condition is fulfilled brittle fractures will occur, whatever their detailed method of propagation.'

Determination of Metals in Fuel Ash

See abstract on p. 40.

Extrusion of Metals: Presses and Auxiliary Equipment

E. K. L. HAFFNER and R. M. L. ELKAN: 'Extrusion Presses and Press Installations.'
Metallurgical Reviews, 1957, vol. 2, No. 7, pp. 263–303.

During the past few years considerable changes have taken place in the mode of operation of extrusion presses and their auxiliary equipment: major mechanical alterations have been introduced, there has been a pronounced trend towards utilization of direct oil drive for slowly-operating presses of tonnages up to about 4,000, and a tendency to adopt fully or semi-automatic operation for all new presses. The factors which have given impetus to such changes are reviewed, as an introduction to a survey of modern types of extrusion press and discussion of the benefits derived from the new designs which have been introduced. In the latter connexion, a chart shows increase in production which has been effected by cutting down of the 'idle time' inevitable with some of the older presses.

The review deals essentially with the design of presses and the mechanical operations involved in extrusion, i.e., it is primarily written from the engineering angle, and does not discuss the extrusion of individual materials. It does, however, include a list of metals and alloys which can be formed by extrusion, showing also the temperature ranges suitable for processing the respective types. The list includes several types of aluminium-, magnesium- and copper-base alloys, nickel, Monel, Inconel, cupro-nickel and nickel silver.

Welding Handbook

AMER. WELDING SOC.: 'Welding Handbook.'
Fourth Edn., Sect. I, 1957.
Edited by A. L. PHILLIPS.
Published by the Society.
Price: Members, 6 dollars; Non-Members, 10 dollars.

The Welding Handbook is generally recognized as the most comprehensive and authoritative source of information on the subject, and to maintain this standard in the revised edition the compilers have used data and experience provided by research and testing laboratories, industrial firms, technical committees and published literature. Revision over the whole range of subject matter covered by the third edition is so large a task that if publication of the new edition were delayed until the whole project was complete a considerable proportion of the information would be relatively out of date. It has therefore been decided to issue the Handbook in a new format. The material will be divided into five subject groups, and one revised section will be published each year until the five are complete. This cycle will then be regularly repeated, so that in future each section will be revised once in five years, thus keeping the contents reasonably up-to-date.

The subjects covered by Section I are listed below:

Standard welding terms: glossary
General engineering tables
Fundamentals of welding metallurgy
Properties of welded joints
Thermal and mechanical treatment of weldments
Design of welded joints
Factors and data involved in estimating costs
Inspection of welding
Standard methods for mechanical testing of welds
Statistical control of weld quality
Safe practices in welding and cutting

Section I includes a brief review of the general welding metallurgy of nickel, high-nickel alloys and chromium-nickel stainless steels, and information on the corrosion-resistance of weldments produced from such types of material.

NICKEL

Research in the Nickel Industry

R. D. PARKER: 'Research and the Nickel Industry.'
Trans. Canad. Inst. Mining and Metallurgy, 1957, vol. 60, pp. 357–62; *Canad. Mining and Metallurgical Bull.*, 1957, vol. 50, Nov., pp. 659–64.

Address delivered during Commonwealth Mining and Metallurgical Congress, on the occasion of a visit to the nickel mines at Sudbury, Ontario, Sept. 24, 1957.

The address consists essentially of a historical review of the development of the nickel industry, with emphasis on the part which research has played in such progress.

'As the history of nickel has been moulded by geographical circumstance, so has its character been formed and moulded by research. The sum of nickel's contribution to human progress, gathering steadily down through the years and increasing at compound interest during the past quarter century, has been reached by research. Now, day by day, continuing research is indicating new ways in which nickel will serve humanity in the world of tomorrow.'

The history of nickel is reviewed by reference to outstanding events and developments in mining techniques, extraction and refining methods, new alloys, and expansion in application of nickel-containing materials. Research has been the background responsible for much of the past development and it will continue to be a factor of major importance in future progress.

Extension of Nickel Mining in Cuba

'Planning Cuba's Second Nickel Mine.'
Engineering and Mining Jnl., 1957, vol. 158, Sept., pp. 78–81.

This article describes developments which are taking place at the Moa Bay Mining Company's plant,* which within the next few years will make a valuable addition to free-world supply of nickel and cobalt. The ore of the Moa Bay region differs substantially from that found in the Nicaro area, as was noted in a paper recently presented to the geological division of the American Institute of Mining and Metallurgical Engineers:

'Moa deposits differ from Nicaro chiefly in the ratio of lateritic iron ore to decomposed serpentine ore. (In making the distinction between 'iron ore' and 'serpentine ore' an arbitrary cut-off of 35 per cent. iron is used.) At Nicaro this ratio is about 1·6 : 1, whereas at Moa the ratio is 10 : 1, and because of the irregular distribution of the decomposed serpentine (the only serpentine in which nickel is concentrated enough to be called ore) at Moa, no serpentine ore is included in the reserves.'

This difference makes possible a different mode of treatment at Moa: for example, sulphuric acid can be used for leaching. A flowsheet gives the details which can at present be divulged with regard to the processing cycle. It is anticipated that concentrate shipped to Cuban American Nickel Company* for treatment will contain about 5 per cent. of nickel and 5 per cent. of cobalt. Tailings are expected to contain less than 0·1 per cent. nickel+cobalt.

Extraction of Nickel from Lateritic Ores

'Nicaro Expands Nickel Capacity.'
Engineering and Mining Jnl., 1957, vol. 158, Sept., pp. 82–9.

Detailed account of the combined mining, engineering, extraction and refining developments which have taken place in the U.S. Government plant at Nicaro, in the Oriente province of Cuba. The article includes complete flow sheets showing, in detail, all stages of the operations at Nicaro: these comprise reduction of the raw ore (in which the nickel is present in the form of a complex oxide); leaching or oxidation with aqueous ammonium carbonate, which extracts about 80 per cent. of the contained nickel; ammonia stripping of the solution after the reduced ore has been washed out; calcining, and sintering. Attention is directed to some recent improvements in operating technique, and reference is made to some problems which are still outstanding, e.g., reduction of the cobalt content of the final nickel product, and ammonia losses in processing. A brief note is added with regard to methods which are being tried for separation and extraction of cobalt, and this subject is dealt with also in the paper referred to in the following abstract.

* Moa Bay Mining Company and Cuban American Nickel Company are both subsidiaries of Freeport Sulphur Company.

M. H. CARON: 'Separation of Nickel and Cobalt.'
De Ingenieur, 1957, Sept. 6, pp. 19–32.

Further to an earlier paper (*Trans. Amer. Inst. Mining and Metallurgical Engineers*, 1950, vol. 188, pp. 67–90; *Nickel Bulletin*, 1950, vol. 23, No. 3, p. 47), the author discusses difficulties associated with sulphur contamination occurring in ammonia/ammonium-carbonate solutions under commercial conditions such as those obtaining in the Nicaro plant. Proposals are tentatively made for a remedial treatment which, it is claimed, would make such contamination harmless and would provide a means for continuous operation of pregnant solutions under atmospheric pressure, with final production of pure nickel and cobalt.

Diffusion of Hydrogen in Nickel

A. G. EDWARDS: 'Measurement of the Diffusion Rate of Hydrogen in Nickel.'
Brit. Jnl. Applied Physics, 1957, vol. 8, Oct., pp. 406–9.

The passage of a gas molecule through a metal membrane into a vacuum involves three processes:

(1) Penetration through the gas-metal interface on the entrance side.

(2) Diffusion through the bulk metal.

(3) Penetration through the metal-vacuum interface on the exit side.

Theoretically, any one of these processes may be effective in limiting the overall rate of transfer of the gas molecules through the foil, but in practice it is not agreed in which systems, if any, surface barriers to interface penetration exists. The author introduces his paper by reference to the views held by some investigators, and by discussion of the theory of the outgassing of a long cylinder into a vacuum, as a preliminary to description of the apparatus and technique employed in his own work.

In these experiments the diffusion rate of hydrogen within nickel was measured by making observations

of the rate of escape of the gas from a hydrogen-soaked nickel wire heated in vacuo. The value obtained agreed, within the limits of experimental error, with data on solubility and rate of permeation through foils, interpreted on the assumption that energy barriers to gas penetration through surfaces are small.

Adsorption of Oxygen on Nickel at Sub-Zero Temperatures

A. C. ZETTLEMOYER, Y. F. YU, J. J. CHESSICK and F. H. HEALEY: 'Adsorption Studies on Metals. V. Oxygen on Nickel, Cobalt and Copper at −195°C.'
Jnl. Physical Chemistry, 1957, vol. 61, Oct., pp. 1319-22.

Previous studies on the oxidation of nickel, cobalt and copper powders at −78° to +26°C. had revealed that multilayers of oxides formed instantaneously on the reduced surfaces, to some limiting thickness, and that the oxidation then continued as an exponential function of time. The oxide-coated surfaces on nickel and cobalt could be regenerated for further oxidation by heating in vacuo. The extent of the fast oxidation process on surfaces of nickel and of cobalt was temperature-dependent; for copper this was not so.

The investigation now reported was undertaken to extend the oxidation studies of reduced and regenerated metal surfaces to lower temperatures, in order to investigate the very-thin-film region of growth. The aim was to obtain more precise knowledge of the initial stages of oxidation, i.e., the reaction or chemisorption of the initial molecules of oxygen, although it was realized that at −195°C. oxidations are partially obscured by the presence of physically adsorbed oxygen.

The observations made are summarized below:

During the first oxidation of the reduced metal four portions of oxygen are apparently adsorbed: (1) an oxide layer, (2) a chemisorbed layer of O^{-1} ions, (3) strong physically adsorbed molecules, and (4) ordinary physically adsorbed molecules. The strong physically adsorbed molecules could be removed between −195° and −78°C., and the chemisorbed ions on nickel and cobalt could be converted to oxide by activation at elevated temperatures, thus regenerating the surface for further reaction with oxygen at −195°C. Copper coated with very thin films could not be regenerated, due, the authors presume, to the absence of field-creating O^{-1} ions.

Chemisorption of CO_2 on Nickel Films

A. C. COLLINS and B. M. W. TRAPNELL: 'CO_2 Chemisorption on Evaporated Metal Films.'
Trans. Faraday Soc., 1957, vol. 53, Nov., pp. 1476-82.

The interaction of CO_2 with evaporated films of the following metals was studied, at temperatures in the range −78° to +70°C.: tungsten, molybdenum, iron, nickel, ruthenium, platinum, palladium, aluminium, copper, zinc and cadmium. The mechanism of CO_2 chemisorption is discussed in the light of the results obtained and the relevance of the data to the catalysis of isotopic exchange between CO and CO_2 is considered.

Resistance of Nickel to Fluorine

See abstract on p. 60.

Corrosion by Acetic Acid

See abstract on p. 60.

Reaction between Fused Sodium Hydroxide and Nickel

See abstract on p. 55.

Identification Tests for Nickel Alloys

See abstract on p. 47.

Determination of Metals in Fuel Ash

W. RADMACHER and W. SCHMITZ: 'Rapid Methods for Analysis of Fuel Ash. III. Determination of Copper, Nickel, Cobalt, Zinc, Manganese and Vanadium.'
Brennstoff-Chemie, 1957, vol. 38, Oct. 16, pp. 308-12.

Step-by-step description of procedures developed in the laboratories of the Brennstoff-Chemische Institut der Ruhrkohlen-Beratung, G.m.b.H., Essen. A polarographic method is recommended for determination of nickel.

Nickel Catalysts for Hydrogenation of Oils

D. D. NANAVATI and J. S. AGGARWAL: 'Nickel Catalyst for the Hydrogenation of Oils.'
Jnl. Proc. Oil Technologists' Assoc., India, 1956, vol. 12, pp. 13-22.

Comparative study of the activity of five hydrogenation catalysts prepared at temperatures in the range 450°-480°F. (230°-250°C.), using peanut oil and nickel formate. Results are summarized in *Chemical Abstracts*, 1957, vol. 51, p. 11,736.

Nickel-Cadmium Batteries: Specification

MINISTRY OF DEFENCE: 'General Specification for Portable Secondary Batteries. (Nickel-Cadmium Type.)
Defence Specification DEF-35, Sept. 25, 1957; 14 pp. Published by *H.M. Stationery Office*. Price 2/6.

The specification covers portable batteries for electronic and communication equipment, the electrical services of aircraft, fighting vehicles and mechanical transport, engineering equipment and miscellaneous shipboard power supplies. It includes requirements for general design, manufacture, type approval, test procedure and inspection. The specification is to be read in conjunction with related B.S. and D.T.D. schedules, to which reference is given.

Among the requirements are impurity limits for the positive active material (prepared from nickel hydrate) and the negative active material (prepared from cadmium and iron oxides). The materials section covers also nature and quality of hard rubber (used for insulators, etc.), timber for crates, trays and cases, solder and soldering fluxes, and the potassium-hydroxide electrolyte (purity, physical condition, etc.).

Diffusion of Nickel-63 in Nickel Oxide

R. LINDNER and ° ÅKERSTRÖM: 'Diffusion of Nickel-63 in Nickel Oxide (NiO).'

Discussions Faraday Soc., 1957, No. 23, pp. 133–6. Paper contributed to General Discussion on Molecular Mechanism of Rate Processes in Solids, 1957.

This paper is a sequel to that published in *Zeitschrift für physikalische Chemie*, 1956, vol. 6, p. 162, which related to studies of the self-diffusion of nickel in nickel-oxide sintered pellets. The results reported in the earlier paper, especially the high activation energy found, were considered to be somewhat doubtful, and it was assumed that the short-lived radioactive tracer nickel-65 (half-life 2·56 hours) was not suitable for such experiments. The investigation has now been repeated, using the long-lived nickel-63 (85 hours half-life). Diffusion was measured on nickel oxide in the form of crystals, metal-oxidation layers and sintered pellets, over the temperature range 740°–1400°C., using the surface-decrease method. The temperature function of the self-diffusion coefficient is represented by the equation $D = 1 \cdot 7 \times 10^{-2} \exp(56{,}000/RT)$ $cm^2 sec^{-1}$.

Welding Handbook

See abstract on p. 38.

ELECTRODEPOSITION AND OTHER COATING METHODS

Ultrasonics in Electrodeposition

S. R. RICH: 'The Latest Developments in Electroplating with Ultrasonics.'

44th Ann. Tech. Proc., Amer. Electroplaters' Soc., 1957, pp. 87–90.

The author directs attention to a paper published in *Plating*, November 1955, which contained an analysis of the theory of the application of ultrasonics to electrodeposition, together with some examples of resulting improvements in plating. Since that date much progress has been made in application of ultrasonics in the electrodeposition of individual metals, and in development of equipment suitable for use in production plating plant. These advances are reviewed.

Ultrasonics have been successfully applied in electrodeposition of nickel, zinc, chromium and silver. Among the points mentioned in the brief record of experience given in the paper are the following:

'*Nickel.* The application of ultrasonics to nickel plating is one of the most direct and easiest plating procedures. The solutions used have been the Watts bath, the fluoborate bath, and a variety of proprietary bright-nickel solutions. It was found that the temperature requirements for the bath were made far less stringent in the presence of ultrasonic energy than without ultrasonics. In all cases nickel plating in the presence of ultrasonic energy permitted an increase in current density of 200–500 per cent. without burning, with corresponding increase in rates of deposition.

'Depolarization by the ultrasonic energy causes increase in current flow within one to four minutes after initiation of plating current, as contrasted with a fall in plating current due to polarization that normally occurs under these conditions. In all cases, plating was accomplished even under conditions of contamination in which ordinary plating would be impossible. Films of surface oil, which would cause a water break, were removed by the ultrasonics during the plating process and good nickel coatings were obtained. It was found that moderately heavy dirt, including buffing compound, shop dirt, heavy rust, etc., would prevent an adherent coat from being obtained.

'In the use of bright nickel baths, we found it necessary to avoid the use of high-molecular-weight bright-nickel additives: the ultrasonic energy tended to break down such materials. Various companies have co-operated in the development of additives of low molecular weight which are not broken down by ultrasonics, and which permit excellent bright-nickel finishes being obtained at current densities of the order of 100 amperes per square foot and corresponding accelerations of coating deposit.

'The application of ultrasonics to the nickel plating of stainless steel has shown that the conventional procedure of using a strike bath and a very careful pre-cleaning process cannot be eliminated by ultrasonics: the ultrasonic energy is useful only in obtaining a more rapid coating. The appearance of plating produced with the aid of ultrasonics is, however, uniformly excellent at the higher current density, and the method should prove to be a valuable factor in speeding up electroplating of stainless steel.

'*Zinc.* A major application of ultrasonics to the electrodeposition of zinc may lie in the acceleration and improvement of barrel plating. This development is still in the experimental stage. In deposition of zinc from cyanide baths ultrasonics are beneficial in plating surfaces which have not been thoroughly prepared.

'*Chromium.* Results in this connexion are in some respects promising, in others disappointing. The use of ultrasonics permits very high rates of current density without burning, but gives no improvement in throwing power.

'*Silver.* In this case conflicting results are recorded. Use of ultrasonics makes possible very much higher current densities and faster rates of deposition, but at ordinary current densities results so obtained are less satisfactory than under conventional conditions.'

The second part of this review deals with the benefits derived from introduction of ultrasonics in processes involved in the preparation of metals for plating, e.g., for removal of buffing compounds, in pickling, de-rusting, and other operations. Speed and efficiency are increased, in some cases to a spectacular degree. In some instances, also, use of ultrasonic energy makes possible the use of less toxic chemicals, e.g., in the pickling of Monel type-metal dies, where the use of a harmless 5 per cent. citric-acid solution has been introduced in place of a stronger acid needed when the operation was carried out by manual methods.

Nickel-Flashed Sheet for Enamelling (Nitec)

W. H. TICKLE and D. A. WINTON: 'Continuous Surface Pre-Treatment Processes with particular reference to 'Nitec' Sheet for Vitreous Enamelling. An Account of Practice at the Shotton Works of John Summers and Sons, Ltd.'

Metal Finishing Jnl., 1957, vol. 3, Nov., pp. 453–4; disc., pp. 454–5 and 464.

This short paper was presented at the Annual Conference of the Institute of Vitreous Enamellers, as an introduction to a film dealing with the applications of pre-coated sheets in that industry. Nitec a typical pre-coated sheet material, is made from steel of enamelling grade, rolled to strip and, after annealing and cleaning, coated with a flash of nickel, and finally with a protective coating of zinc. It has been developed with the threefold aim of providing a material the surface of which, as delivered, could be regarded as satisfactory, would require a minimum of processing before enamelling, and would permit single-coat enamelling.

The paper dealt mainly with two factors: (1) the technical efficiency and reduction in costs which would result from mass production of the sheet by a continuous process instead of nickel-flashing of small quantities of individual units, and (2) the elimination, from the enameller's work, of the greater part of the cleaning and surface preparation, which would then be the responsibility of the sheet producer.

The authors briefly review the fabricating and plating processes used at the works of John Summers and Sons, Ltd., in production of Nitec. In connexion with the use of a final coating of zinc, it is explained that this is applied to protect the nickel-flashed surface from mechanical damage, to lengthen the life of tools, and to protect the nickel coating from abrasion during deep drawing. In pickling, prior to enamelling, the zinc deposit can be removed in three minutes (as compared with the average time of 20 minutes required for pickling of uncoated enamelling iron), leaving ready for treatment a nickel-flashed surface suitable for single-coat treatment.

Discussion centred mainly on (1) the efficacy of the nickel-flashed surface of Nitec *vis-à-vis* the coating produced by the conventional nickel-dip process, and (2) the effect, on Nitec sheet, of severe mechanical working before enamelling.

Electrodeposition of Nickel-Iron Alloys

I. W. WOLF: 'Further Studies on Nickel-Iron Alloy Electrodeposits.'

44th Ann. Tech. Proc., Amer. Electroplaters' Soc., 1957, pp. 121–3.

This report is a sequel to that presented before the same Society in 1956: see abstract in *Nickel Bulletin*, 1957, vol. 30, No. 4, p. 54. The earlier paper contained data on the magnetic properties of films of 79–21 nickel-iron alloy and evaluated their potential usefulness in magnetic shielding. This later paper is concerned with studies on the effect of current density, thickness of film, grain size and other variables, in relation to the magnetic properties of the deposit, and also with the corrosion-resisting quality of electrodeposited nickel-iron films, as gauged by the standard salt-spray test. It is suggested that a useful application of the electrodeposited alloy would be as a magnetic-memory element: consideration is given to conditions of deposition likely to give optimum properties for such use.

Electrodeposition of Tin-Nickel Alloys from Pyrophosphate Solutions

T. L. R. CHAR: 'Electroplating from the Pyrophosphate Bath. VI. Electrodeposition of Alloys.'

Electroplating and Metal Finishing, 1957, vol. 10, Dec., pp. 391–2 and 408.

The work covered is essentially the same as that reported by VAID and CHAR in the *Journal of Scientific and Industrial Research, India, Sect. A*, 1957, vol. 16, pp. 324–5 (see *Nickel Bulletin*, 1957, vol. 30, No. 12, p. 218).

Corrosion-Resistance of Tin-Nickel and Other Tin-Alloy Coatings

F. A. LOEWENHEIM: 'The Corrosion-Resistance of Tin-Alloy Electrodeposits.'

44th Ann. Tech. Proc., Amer. Electroplaters' Soc., 1957, pp. 42–6.

Although in earlier years tin coatings on steel had not been associated primarily with corrosion-resisting applications, within the past few years several new and improved processes have been developed for electrodeposition of tin alloys, and in several cases the coatings produced have proved to have considerable value as protective media. The purpose of this paper is to review pertinent literature on the corrosion-resistance of the respective types of tin-alloy coating and to present some hitherto unpublished data.

The review is made in sections covering, respectively, tin as an undercoat to chromium, nickel/chromium, zinc, cadmium, etc., and the corrosion-resisting characteristics of tin-zinc, tin-cadmium, tin-lead, tin-nickel and tin-copper alloys and coatings. The advantages and limitations of the respective types are critically reviewed, the judgment being based, in general, on behaviour of the coatings

under atmospheric exposure in various climates. (The author purposely disregards results obtained by salt-spray or other accelerated methods of test, since he considers such data invalid in relation to service life.)

With regard to tin-nickel (65-35%) coatings, attention is directed to comprehensive papers which have been published on the technique of deposition and the properties of the deposits. Additional tests have been made by the company with which the author is associated to compare the behaviour of tin-nickel deposits with those of copper/nickel/chromium coatings, in industrial and marine atmospheres. Full details of these tests are to be published in the near future: in the meantime the following summary of results is given:

'1. Marine atmospheres are more corrosive to both tin-nickel and nickel/chromium coatings than are industrial atmospheres. At Kure Beach the heavier tin-nickel coatings were approximately equal in performance to the same thickness of nickel/chromium. In thinner coatings (0·25 to 0·5 mil) over undercoats of copper, nickel/chromium was somewhat superior, but these thin deposits failed too rapidly in this atmosphere to be of utility.

'2. At Bayonne, after two years' exposure, tin-nickel is in general much superior to nickel/chromium. At Pittsburgh the same trend is beginning to show, although deterioration is much slower in this location and many of the panels have hardly begun to corrode.

'3. Tin-nickel coatings fail in a different way from nickel/chromium. The latter characteristically fails by pinholing; more and more rust spots form, until a typical low-rated panel has hundreds of small rust spots scattered over its surface. Tin-nickel coatings, on the other hand, appear to fail in only a few spots; these spots grow as deterioration proceeds, until a failed panel may exhibit one or two relatively enormous rust areas surrounded by large areas of perfectly sound, uncorroded coating. This behaviour suggests that the tin-nickel alloy itself is a very noble metal and that corrosion takes place only through pores already present.

'4. Whereas nickel may be plated direct on steel or over an undercoating of copper, tin-nickel should not be applied direct to steel, at least for protective effect outdoors. Even a thin flash (0·01 mil or so) of copper or bronze interposed between the steel and the tin-nickel is sufficient to improve its performance many-fold.

'5. The tin-nickel coatings retain their brightness well in both marine and industrial atmospheres. They do, however, acquire a tint which may be described as an accentuation of the slight rose-pink cast of the freshly-plated deposit: the difference, in other words, between the 'blue' of chromium and the 'pink' of tin-nickel is accentuated on ageing in the weather. While not a problem in itself, this fact would entail some difficulties in assemblies which included both chromium- and tin-nickel-plated components. The obvious solution would be to apply the usual thin chromium plate over the tin-nickel; means of doing this satisfactorily are under study, with every indication so far that tin-nickel can be successfully chromium-plated.'

Effect of Electrodeposited Coatings on High-Strength Steels

W. BECK and E. J. JANKOWSKY: 'Effects of Plating High-Tensile-Strength Steels.'
44th Ann. Tech. Proc., Amer. Electroplaters' Soc., 1957, pp. 47-52.

The paper describes tests made to determine the effect of cadmium and of chromium coatings, on low-alloy nickel-chromium-molybdenum steel of S.A.E. 4340 type. The authors describe (with detailed illustrations) a 'C-ring' test specimen.

These specimens were electroplated with cadmium (cyanide solution), chromium, or tin, and in some specimens an electroless nickel layer was deposited under the cadmium coating. Various protective treatments were used, e.g., shot-peening before plating, and baking after plating. The rings were stressed before and after plating, and the effectiveness of the respective treatments was assessed on the basis of time to cracking.

Time to cracking for specimens plated with cadmium from the cyanide solution was very short, a finding which is in keeping with records in the literature. It is concluded that the presence of cyanide compounds creates conditions which are favourable for the introduction of hydrogen atoms into the metal. Hydrogen embrittlement has, however, been found to be only slight when fluoborate baths are used for cadmium deposition. Marked protection against cracking was conferred by use of an electroless nickel underlay, due, it is believed, to the fact that nickel coatings of suitable thickness act as barriers to hydrogen diffusion. Shot-peening of the basis metal before plating was also beneficial, consistent with the observation, made in other tests, that a high-strength steel surface on which compressive stresses are present behaves in a ductile manner when cathodically charged with hydrogen. Study of the influence of various inhibiting agents added to the cyanide-cadmium solution showed predominantly beneficial effects from hydrogen peroxide. In general, however, oxidizing agents, though effective to a certain degree, are decomposed during plating, and their use cannot be recommended. The mechanism of the effect of these addition media is complex, and will be the subject of a later paper. For the present the authors conclude that the effect cannot be simply explained by the counteracting of hydrogen diffusion as a result of the rapid oxidation of the hydrogen atoms on the surface of the metal.

It is considered safe to assume that crack formation is initiated by the combined action of high stress and the presence of hydrogen, and that probably the rate of crack formation is inter-related with the rate of hydrogen diffusion. The crack propagates

in both longitudinal and radial directions until the remaining cross-sectional area of the specimen can no longer sustain the applied load.

Baking after plating was a more potent deterrent of cracking for chromium-plated specimens than for specimens cadmium-plated from cyanide solution.

The Acetic-Acid/Salt-Spray Test

J. H. HOOPER: 'The Acetic-Acid/Salt-Spray Test. A Comparison with Other Methods of Simulating Service Breakdown of Protected Metal Surfaces.' *Electroplating and Metal Finishing*, 1957, vol. 10, Dec., pp. 403-8.

The salt-spray test for determination of the corrosion-resistance of electrodeposited coatings has been subjected to increasing criticism as a result of its inability to provide data which can be reliably interpreted in terms of performance under atmospheric exposure. A joint investigation by the American Society for Testing Materials and the American Electroplaters' Society showed, for example, virtually no correlation in results obtained from four independent series of salt-spray tests made on a range of nickel/chromium coatings on steel, and many other investigators have reported similar discrepancies. Study of exposure conditions showed that much of the inconsistency resulted from mechanical causes such as clogging of nozzles, or as a result of the spray becoming dry due to poorly humidified air or inadequate supply of liquid. By substitution of a 5 per cent. sodium-chloride solution (A.S.T.M. B-117:54T) for the 20 per cent. solution specified in the 1949 version of the same specification, many of these defects were eliminated, but it was recognized that the technique was still unsuitable as a method of testing plated components. The A.S.T.M./A.E.S. Committee has therefore been studying the potential usefulness of an acetic-acid modification of the salt-spray test, proposed, in 1945, by Nixon. The original work was done with a 20 per cent. sodium-chloride solution containing 5 per cent. of acetic acid, pH 2, operated at 120°F. (50°C.), but recent research has centred on a test involving exposure to spray of a 5 per cent. sodium-chloride solution with an addition of 1 per cent. of acetic acid, operated at 95°F. (35°C.). Results for nickel/chromium, cadmium and zinc coatings thus tested show good agreement with data obtained from exposure of similar coatings under atmospheric conditions. (Further information on the use of this solution is contained in a paper by McMaster, *A.S.T.M. Bulletin*, 1955, No. 203, Jan., pp. 62-9; *Nickel Bulletin*, 1955, vol. 28, No. 4, p. 61), and it may also be noted that the American Electroplaters' Society Research Project Committee on Accelerated Corrosion Tests has recently made tentative recommendations for the use of the test; see *Nickel Bulletin*, 1957, vol. 30, No. 10, p. 178.

Work in the U.K. has been concentrated mainly on tests in which corrosion-resistance of plated coatings is evaluated by exposure to atmospheres containing sulphur dioxide. These tests include the C.R.L. test (*B.S.* 1391: 1952), in which the specimens are suspended over a heated dilute sulphur-dioxide solution; the Kesternich test, in which a mixture of SO_2 and CO_2 is fed into a cabinet containing water which is heated for 8 hours a day, and the British Non-Ferrous Metals Research Association SO_2 test, which involves the introduction, at constant rate, of a SO_2/air mixture into a closed, humidified cabinet.

The present article, which is an abstract of a paper presented to a Joint Meeting of the Institute of Metal Finishing and the Society of Chemical Industry, reports an investigation into the relative efficacy of the 5 per cent. salt-spray test, the cold- and hot-acetic-acid/salt-spray and the SO_2 tests, as means of evaluating the corrosion-resistance of anodized aluminium parts, and of nickel/chromium and copper/nickel/chromium coatings on steel, brass and zinc-basis die castings. The test specimens consisted of automobile parts, such as hub caps, name plates and badges. The specifications to which the coatings were deposited and the procedure used to anodize the aluminium are detailed, and the test conditions are described, with an illustration of the spray cabinet.

The data obtained are compared with the results for similar specimens subjected to exposure in a rural industrial atmosphere.

Assessment of the comprehensive results given leads the author to draw the following conclusions:

'*5% Salt Spray*

'The test appears to have virtually no value for assessing the coating systems investigated, but is useful only for showing gross discontinuities in nickel coatings of around 0·5 mil thickness.

'*SO_2 Test*

'The great value of this test lies in its rapidity, but its field of application is limited. It may be applied as a 24-hour test for quality control of nickel/chromium or copper/nickel/chromium deposits on steel, or of nickel deposits over 1 mil in thickness (as in B.S. 1224 Ni 12S). For this application it is the most rapid test investigated. It is, however, considered unsuitable for testing plated zinc or copper alloys or bright anodized aluminium. Where a chromium deposit is cracked the SO_2 test corrodes through the nickel very rapidly (1 mil in 72 hours). The copious nickel corrosion products tend to screen basis-metal corrosion in test periods in excess of 24 hours.

'*Acetic Acid-5% Salt Spray*

'This test, operated either cold or hot, is considered to be the most universally useful. Used hot, it is a good 72-hour quality-control test for deposits of B.S. 1224 Ni 12S and a satisfactory 48-hour test for the Ni 8S quality.

'In testing nickel deposits under 1 mil in copper/nickel/chromium systems on zinc-basis alloy, a 60-hour test appears to correlate well with outside exposure. Neither the cold nor the hot test is entirely satisfactory on copper-base alloys, where it requires skilled interpretation, but a test of 60 hours' duration (hot) shows corrosion of a type produced out of doors within 26 weeks.

'On bright anodized high-purity aluminium the time to breakdown, in both the hot and cold tests, is closely related to the anodic film thickness. 24-hour (hot) or 40-hour (cold) acceptance tests could be used for a 0·2-mil coating specification and a 40-hour (hot) and 60-hour (cold) acceptance test for 0·4-mil coatings. The pit corrosion produced by the tests resembles closely that produced in service.'

NON-FERROUS ALLOYS

Welding Handbook

See abstract on p. 38.

Control of Quality in Non-Ferrous Castings

INST. METALS: 'Metallurgical Aspects of the Control of Quality in Non-Ferrous Castings.'

Inst. Metals Monograph and Report Series No. 22, 1957; 148 pp.

This volume contains the final forms of papers presented at a symposium held during the Annual General Meeting of the Institute in London, May 1957, together with the discussion to which the papers gave rise.

For abstracts of the individual papers see *Nickel Bulletin*, 1957, vol. 30, No. 6, pp. 90–1.

Recent Progress in Production of Cast Components

See abstract on p. 47.

Microstructures of Cast Metals: Handbook

See abstract on p. 37.

Brittle Fracture of Metals: Monograph

See abstract on p. 37.

Electrical Conductivity and Hall Constant of Nickel-Chromium Alloys

W. KÖSTER and P. ROCHOLL: 'Conductivity and Hall Constant. II. Nickel-Chromium Alloys.'

Zeitsch f. Metallkunde, 1957, vol. 48, Sept., pp. 485–95.

Previous work on solid solutions of chromium in nickel is discussed, with particular reference to a condition called the 'K state', which is probably a form of short-range ordering. This state is produced by annealing a quenched alloy below a given temperature, and in that condition electrical resistivity is higher than in the quenched state. The K state is destroyed by cold work, with the result that electrical resistance decreases.

Further work on nickel-chromium alloys is described in this paper, including the measurement of electrical resistance, Hall constant, thermal e.m.f. (against copper), paramagnetic susceptibility, hardness, and elastic modulus. From the Hall constant and resistivity the effective charge carrier density and effective mobility were calculated. The measurements covered alloys over a range of 10–40 at.% chromium, for various times and temperatures of heat-treatment, and in the annealed and cold-worked states. The large amount of data thus obtained is graphically recorded. The Hall constant is negative at 10 at.% chromium, increases to zero at 34 at.% chromium, and is positive at higher chromium contents. On establishment of the K state the Hall constant becomes more positive. The effective charge carrier density increases with increasing chromium content up to 34 at.% chromium, and also increases at onset of the K state. Effective mobility and paramagnetic susceptibility decrease with increasing chromium content, and also decrease when the K state is formed.

Some evidence is given that at high chromium contents long-range ordering can occur at the composition Ni_2Cr, particularly in an alloy annealed after cold working.

Resistance of Monel and Inconel to Fluorine

See abstract on p. 60.

Corrosion by Acetic Acid

See abstract on p. 60.

Reaction between Fused Sodium Hydroxide and Nickel-containing Materials

See abstract on p. 55.

Copper-Nickel-Iron Magnet Alloys: Cold-Working and Heat-Treatment

I. L. COOTER and R. E. MUNDY: 'Cunife Wire Magnets of Small Size.'

Jnl. Research, Nat. Bur. Standards, 1957, vol. 59, Dec., pp. 379–82; *R.P.* 2808.

Many of the commercial permanent-magnet materials are extremely hard and brittle, and can be produced in the required shape only by casting or by sintering of mixed powders of the constituent metals. Alloys of the copper 60, nickel 20, iron 20, per cent. type are, however, characterized by an unusual combination of magnetic and mechanical properties: together with a coercivity of several hundred oersteds they exhibit a degree of ductility which permits severe cold-working. Investigations reported in the literature have shown that even if the material is cold-worked to a point at which the magnet properties are adversely affected they can be restored, or even improved, by a simple heat-treatment.

Investigations which led to such conclusions had, however, been made previously only on wires of relative large diameter, and no data were available on the influence of cold work involved in drawing wire to diameters of a few thousandths of an inch. The need for such data became apparent when consideration was given to the use of Cunife as a material for cylindrical magnets 0·5 in. long and

0·005 in. in diameter in connexion with a project under prosecution by the U.S. Bureau of Mines Fuze Branch.

The work reported in this paper was carried out to determine whether the effect of heat-treatment would be as beneficial on the more severely cold-worked wire as it had been found to be on wires of larger diameter. The wire was cold-reduced from 0·025 in. to 0·020 in. in five passes, and from 0·020 in. to 0·005 in. in twenty-one passes. No intermediate annealing was applied.

The investigation covered determination of the magnetic properties of the wire at several sizes, study of the heat-treatments required, as a function of the degree of cold work previously undergone, the influence of oxidation of the wire on its permanent-magnet properties, and the development of treatment for obtaining optimum permanent-magnet characteristics in wire of 0·005-in. diameter. Demagnetization curves were obtained for the wire in the cold-drawn and heat-treated conditions, and values of coercivity, retentivity and maximum-energy product were compared for wires of varying size. It was found that although the magnetic properties were to some extent adversely affected by the more severe degree of cold working, they could be substantially improved by heat-treatment. The procedure recommended as optimum, after cold-drawing, is heating of the wire (embedded in iron filings to prevent oxidation) to a maximum temperature of 610°C., holding at that temperature for one hour, and cooling slowly to room temperature. Final properties can be maintained at a higher level in the 0·005-in. diameter size by starting the reduction from a heat-treated wire of less than 0·025-in. diameter, e.g., 0·012-in. diameter. Some comparisons of the benefits thus gained are given in the table below.

Nickel-Aluminium-Bronze Marine Propellers

F. HUDSON: 'The Development of High-Tensile Aluminium-Bronze Alloys for Marine Propellers in Great Britain and the United States of America.' *Shipbuilder and Marine Engine-Builder*, 1957, vol. 64, Dec., pp. 681–7.

The paper opens with a brief historical review of the developments which have led to extensive application of high-tensile nickel-aluminium for marine propellers. During World War II the high-tensile-brass propellers used on motor torpedo boats were found to be susceptible, under severe operational conditions, to failure by corrosion fatigue, which took the form of cracks starting in tension in the root section of the leading face of the blade. High-tensile nickel-aluminium bronze was recommended as an alternative material, and, following successful trials, that type of alloy was adopted by the British Admiralty as standard for motor torpedo-boat propellers. The use of the same material was later extended to propellers of much larger sizes, and since 1946 thousands of tons of nickel-aluminium bronze have been used in propellers fitted to many types of ship, both in Britain and in the U.S.A. Some of the propellers already have a record of more than ten years' trouble-free service.

The advantages derived from the use of high-tensile nickel-aluminium bronze are outlined in this article, which compares the properties of that material with those of the high-tensile brass formerly used. These advantages include such factors as higher permissible working stresses, lower weight, and lessened maintenance costs. The reduction in maintenance cost results from the resistance of nickel-aluminium bronze to corrosion and to mechanical damage by impact: it is pointed out also that, should damage occur, the propellers can easily be repaired by welding. (Recommendations are made on procedure for welding by the metallic-arc and inert-gas metallic-arc processes, with notes on the mechanical properties of the weldments so made.)

Reference is made to commercial nickel-aluminium-bronze alloys being used for this purpose (Nialite, Nikalium and Novoston) and the article ends with a review of the factors involved in successful founding of the propellers. Attention is directed to the deleterious effect of hydrogen present during melting, and de-gassing procedure is discussed, together with information on deoxidants usually employed in production of aluminium-bronze alloys. The influence of composition on the mechanical properties of the alloys is briefly considered, and limits are given for the more common trace elements which may be present. A base composition recommended as suitable is aluminium 9·5, nickel 4, iron 4, manganese 1·5, per cent., copper balance. The article closes with a note on test bars for evaluating the quality of propeller material: the method recommended for making separately-cast test bars is illustrated.

Properties of Copper-Nickel-Iron Magnet Alloys in Wire Form
(*see abstract on pp. 45-6*)

Wire Diameter	H_c		B_r	
	Initial Wire Diameter, 0·012 in.	Initial Wire Diameter, 0·025 in.	Initial Wire Diameter, 0·012 in.	Initial Wire Diameter, 0·025 in.
in.	Oersteds	Oersteds	Kilogausses	Kilogausses
0·010	625	580	4·6	4·8
0·008	610	490	4·6	4·8
0·005	520	360	4·6	4·8

Identification Tests for Nickel Alloys

MOND NICKEL CO., LTD.: 'Simple Tests for Identifying Some Nickel Alloys and Other Metals.'
Publn. 1293*, 1957; 4 pp.

In response to frequent requests for information on methods which may be used for identification of materials in the sorting of mixed scrap and segregation of materials of different types, a reprint has been made of information which was published in *Nickel Bulletin*, 1953, vol. 26, No. 4. Details are given of tests which may be made to identify the materials according to their varying magnetic properties, of further screening tests based on the reactions of different metals with nitric acid (followed, in some cases, by the iron-nail test for copper), and of a drop test with cupric-chloride solution, which distinguishes Inconel and Nimonic alloys from the 18-8 type of chromium-nickel steel. The publication includes a chart showing the sequence of testing and the typical reactions which will identify the respective types of ferrous and non-ferrous nickel-containing materials.

Determination of Cobalt in High-Nickel Alloys

See abstract on p. 63.

NICKEL-IRON ALLOYS

Oxidation Characteristics of Iron-Nickel Alloys

M. J. BRABERS, W. J. HEIDEGER and C. E. BIRCHENALL: 'The Reaction of Iron-Nickel Alloys with Oxygen.'
Jnl. de Chimie Physique, 1956, vol. 53, pp. 810–16.

The authors point out the complicated nature of the oxidation process in alloys and present results of oxidation experiments on alloys representative of the range 2–72·5 per cent. of nickel. The specimens were oxidized at 1050° and 1095°C., some in oxygen, others in air. After oxidation the furnace was cleared by flushing with argon, and equilibrium was maintained by keeping the alloys in the sealed furnace, at constant temperature, for several days. After removal and air cooling, the specimens were examined microscopically, by X-ray diffraction, and by chemical analysis. The three-phase domain alloy-wüstite-spinel was approximately delineated. The results were, in general, in agreement with those of earlier workers, whose findings are reviewed in relation to the authors' observations.

Influence of Irradiation on the Magnetic Properties of Nickel-Iron Alloys

R. S. SERY, R. E. FISCHELL and D. I. GORDON: 'Effects of Nuclear Irradiation on Magnetic Properties of Core Materials.'
U.S. Department of Commerce, Office of Technical Services, Report P.B. 131014, Dec. 1956; 39 pp.

The substance of this report is similar to that of the paper abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 10, p. 182.

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Reaction between Fused Sodium Hydroxide and Nickel-containing Materials

See abstract on p. 55.

CAST IRON

Production of Ni-Resist Austenitic Cast Iron

MOND NICKEL CO., LTD.: 'The Production of Ni-Resist.'
Publn. 1196*, 1957; 16 pp.

The Ni-Resist cast irons are a group of high-alloy materials developed for applications calling for corrosion- and/or heat-resistance. The normal range covers two grades: standard, and copper-free. For certain highly specialized uses other variants within the broad Ni-Resist range of composition may be used.

The first part of this publication gives full details of composition of the two main grades, their physical and mechanical properties, and structure, with discussion of the influence of the individual constituent elements on properties. The second part contains precise instructions on production methods, including composition of furnace charges, melting conditions suitable in various types of furnace, founding technique, fettling, thermal treatment, and machining. Some notes are added on general foundry practice which will assist in production of satisfactory castings. Brief mention is made of welding practice suitable for Ni-Resist, and of methods of inspection.

Recent Progress in Production of Cast Components

J. L. RICE, R. W. RUDDLE and P. A. RUSSELL: 'Recent Developments in the Manufacture of Castings.'
Instn. Mechanical Engineers, Advance Copy, Nov. 1957; 21 pp.

The paper was read and discussed at a General Meeting of the Institution arranged in conjunction with the Industrial Administration and Engineering Production Group, on Nov. 29, 1957.

The authors review developments which have taken place during the past 5–10 years in foundry practice, and in the alloys used to make castings. In view of the mainly engineering interest of the audience for whom the information was prepared, the chief emphasis is laid on the effects of such advances on the soundness, mechanical properties, dimensional accuracy and cost of finished castings, rather than on the foundry technique used to achieve such improvements. The subject is dealt with in relation to cast irons and non-ferrous materials. Steel castings as such are not included in the survey, although much of the information given is applicable to all groups of cast materials.

The scope of the four sections of the review is indicated below:

I. Process Development

(a) *Development of New and Established Processes*

Present status of established methods of casting;

improvements in mould-production techniques; improved quality of castings; die-casting developments.

(*b*) *New and Specialized Processes*

Shell moulding; the carbon-dioxide moulding process; precision-investment casting; the Shaw method of close-tolerance casting; semi-permanent refractory moulds; continuous casting of tin-bronze stick by the Asarco process.

II. Alloy Development

Developments in *grey iron*, and in *malleable cast iron*; advent and development of *spheroidal-graphite cast irons*, with notes on the B.S. specification and on some typical applications of the new material.

Improved *copper-base* alloys, including newly developed types of nickel-aluminium bronze, and bronzes of the Ni-Vee type; properties of typical alloys.

Modifications in established types of *aluminium alloy*, covered by the latest revisions of B.S. 1490.

Progress in *magnesium-base* alloys, with special reference to the use of zirconium additions as a means of refining the grain and obtaining improved mechanical properties and soundness. Composition and properties typical of zirconium-containing alloys.

Alloys for service at high temperatures. Comment is made on the very large number of these alloys which have been developed during the past 10–15 years. The authors of this paper list the compositions and, where available, the properties, of selected nickel- and cobalt-base alloys used for production of castings by the lost-wax or other precision-casting processes. Reference is made to experimental work in progress on titanium-base alloys.

Brief mention is made also of minor developments which have demonstrated a general trend towards improvement of quality in cast products, of some recent specifications, and of the views of foundrymen and others on the desirability of standardization by reduction in the number of specifications for non-ferrous casting alloys.

III. Inspection of Castings

Attention is directed to improved inspection methods which are helping to raise the standard of cast product supplied to the engineer, e.g., radiography, and ultrasonic techniques.

IV. Future Trends

The growing need for economy in labour is likely to result in increasing mechanization, favouring the more extensive use of foundry processes which are inherently automatic or can be mechanized.

Central technical planning and control of moulding and casting procedure will probably ensure increasing uniformity and higher quality in cast products.

Spectacular developments in melting technique are considered unlikely, but more precise control will gradually raise the purity of metals and alloys and thus improve quality. Prospects of more general use of electric melting should favour production of higher-grade castings.

The review is illustrated by photographs of some new types of foundry equipment, and of typical cast components. An extensive *bibliography* provides reference to detailed reports on the subjects covered in the review.

Ni-Hard Abrasion- and Wear-Resisting Cast Iron

MOND NICKEL CO., LTD.: 'The Production of Ni-Hard.' Publn. 1195,* 1957; 22 pp.

Ni-Hard is a white cast iron alloyed with nickel (about 3·5–5%) and chromium (1·5–2·5%) to give high hardness and pronounced resistance to abrasion. The structure consists of hard carbides in a matrix rendered martensitic by the nickel content. Since the carbide constituent is harder, but more brittle, than the martensitic matrix, it is desirable to use high-carbon grades of the iron for applications in which maximum hardness is essential and lower-carbon grades when toughness is important and some hardness can be sacrificed. Ni-Hard can be sand- or chill-cast and in most cases the castings should be white throughout. For some special applications, such as certain types of roll, or large castings in which toughness and machinability are required, a grey back may be desirable. Composition limits for the respective grades of Ni-Hard, and of adjustments required to allow for varying section-thickness, are given in this publication.

Details of composition and properties typical of the material are followed by sections containing precise recommendations on melting and founding practice for Ni-Hard, and notes on heat-treatment, fettling and machining. The final section describes some routine control tests (based on fracture-appearance and hardness), and tensile and impact specimens suitable for use in testing Ni-Hard.

This type of alloy cast iron is extensively used for wear-resisting parts of stone- and ore-crushers, gravel- and ash-handling plants, grinding mills of all types, clay-mixing and brick-making machinery, as shot blast, and for many other applications.

Ni-Resist for Diesel-Engine Manifolds

'Ni-Resist Iron Ends Problem in Diesel-Engine Maintenance.'

Nickel Topics, 1957, vol. 10, No. 9, p. 4.

Austenitic cast iron containing 30 per cent. of nickel (Ni-Resist Type 3) has been found particularly suitable for the manifolds of high-powered Diesel engines used on the Southern Pacific Railroad. This article lists the advantages derived from utilization of the special properties of cast iron of this type. This alloy cast iron withstands relatively high operating temperatures for long periods without warping or cracking, and is comparatively unaffected by cyclic heating and cooling. The fact that no loose scale forms on the surface of Ni-Resist is also beneficial, in that there are no corrosion

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products which might be picked up by the exhaust gas and cause damage to the turbochargers. The thermal expansion of Ni-Resist is similar to that of ordinary iron and steel, and this characteristic makes it peculiarly suitable for long manifolds which are joined to iron and steel components.

Adoption of Ni-Resist for this application has doubled the service life of the manifolds and has reduced the number of overhauls necessary to one in every two years. Moreover, it is found that, on overhauling, the majority of the components usually need only cleaning and minor repair. Many of the manifolds installed in 1953 are still in service and, as a result of this experience, the railway is now using Ni-Resist manifolds in all its new Diesel engines.

Microstructures of Cast Metals: Handbook

See abstract on p. 37.

Identification Tests for Nickel Alloys

See abstract on p. 47.

CONSTRUCTIONAL STEELS

Hydrogen Embrittlement of Steel

J. G. MORLET, H. H. JOHNSON and A. R. TROIANO: 'A New Concept of Hydrogen Embrittlement in Steel.'

Wright Air Development Center Tech. Report 57-190, Mar. 1957; 42 pp.

The report opens with a critical survey of the theories which have been proposed to explain the mechanism of hydrogen embrittlement. It is considered that none of these adequately account for the modification in the recovery curve which is introduced by plastic deformation. As a contribution to the clarification of this aspect, the authors determined the effect of plastic strain on the tensile ductility of steel hydrogenated either before or after straining.

The material selected was a commercial type, to S.A.E. 4340 specification: the composition is given as follows: carbon 0·402, silicon 0·29, manganese 0·82, sulphur 0·015, phosphorus 0·012, nickel 1·72, chromium 0·85, molybdenum 0·25, hydrogen 0·00013, oxygen 0·003, nitrogen 0·009, per cent. The tests were made on steel at a tensile strength level of 230,000 p.s.i. (102·5 tons per sq. in.).

It is concluded that a consistent interpretation of the data obtained is provided by the hypothesis that hydrogen exerts a maximum embrittling effect in the region of most severe triaxial stress. Hydrogen occluded in internal voids is non-damaging: embrittlement results from hydrogen in solution.

High-Temperature Properties of Steels for Steam Plant

See abstract on p. 57.

Brittle Fracture of Metals: Monograph

See abstract on p. 37.

Photoelectric Colorimetric Methods for Analysis of Steels

E. PIPER and H. HAGEDORN: 'Recent Developments in Photoelectric Colorimetric Analysis. The Determination of Phosphorus, Tungsten, Silicon, Nickel and Boron in Steels.'

Archiv f.d. Eisenhüttenwesen, 1957, vol. 28, July, pp. 373-7.

The authors point out the growing importance of photoelectric methods of analysis and make a critical survey of the advantages and limitations of spectrophotometric and colorimetric procedures, with due consideration of the need for rapid accurate analysis in routine control. They then give a detailed report of improved colorimetric techniques which have been worked out in the laboratories of Völklinger Hütte.

Particulars are given of method of preparing samples, of solution procedure, and of filters which have been found suitable for use in certain analyses. A full step-by-step description is given of methods for colorimetric estimation of tungsten, silicon, nickel and boron.

Identification Tests for Steels

See abstract on p. 47.

Photometric Determination of Tungsten in Steels

See abstract on p. 63.

Determination of Niobium and Tantalum in Steel

See abstract on p. 63.

Welding Handbook

See abstract on p. 38.

HEAT- AND CORROSION-RESISTING MATERIALS

High-Temperature Alloys: Composition and Properties

AMER. SOC. TESTING MATERIALS: 'Compilation of Chemical Compositions and Rupture Strengths of Super-Strength Alloys.'

A.S.T.M. Special Tech. Publn. 170*A*, 1957; 6 pp. Price 75c.

Prepared by W. F. SIMMONS and V. N. KRIVOBOK.

This reference information, which is issued under the aegis of A.S.T.M. Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, was originally compiled to assist a Sub-Committee in drawing up specifications for high-temperature alloys. The first edition was published in 1955, and since that date the scope of the Committee's work has been broadened to include ferritic (martensitic) as well as austenitic alloys. Data on such alloys are included in the revised edition. The age-hardening austenitic stainless steels are also included, but not the conventional corrosion-resisting chromium-nickel types.

The information, presented in tabular form, is designed to meet the following specification: 'a list of all super-strength alloys known to, or used by, the various industries, with details of composition and available properties.' Since mechanical-property values are of little significance without particulars of processing and heat-treatment, only 100-hour and 1,000-hour rupture strengths are recorded, and it is emphasized that the figures quoted give only an indication of the relative high-temperature strengths of the respective materials. Most of the materials considered are proprietary, and to facilitate reference and the obtaining of further information, the names of probable patentees are shown for the various alloys. It is pointed out also that in most cases the patentee is also the producer, although in some instances a material is made by more than one producer. The information given has been gathered from many sources, the nature of which is noted, and clear indication is given of the degree of precision or of generality with which the data can be accepted. The compilation covers about 150 alloys made in the U.S.A. and 75 types produced in other countries.

Properties of the Nimonic Alloys

W. BETTERIDGE and A. W. FRANKLIN: 'Development of Nickel-Chromium-base Alloys for High-Temperature Service.'

Henry Wiggin and Co., Ltd., Publn. 1265*, 1957; 24 pp.

Reprint of paper published in *Metal Treatment and Drop Forging*, Sept. and Oct., 1956: see abstract in *Nickel Bulletin*, 1956, vol. 29, No. 12, p. 217.

Influence of Atmosphere on Stress-Rupture Properties of Nickel-Chromium Alloys

P. SHAHINIAN and M. R. ACHTER: 'Temperature and Stress Dependence of the Atmosphere Effect on Nichrome V.'

Trans. Amer. Soc. Metals, 1957, vol. 51, *Preprint* 69; 24 pp.

In a previous investigation of the creep properties of nickel in air and in vacuo it had been found that the influence of the atmosphere varied according to the rate of strain imposed. At relatively low rates of strain the strength of the metal was higher in air than in vacuo: at high strain rates the position was reversed. An explanatory mechanism, tentatively advanced, involved two competing processes, (1) oxidation-strengthening, and (2) reduction of strength by decrease in surface energy, due to surface adsorption of gases, and resultant increased tendency to propagation of cracks.

Since it was presumed that the relative effectiveness of these two processes should depend on the rate of oxidation, further tests were made with a material of inherently higher oxidation-resistance, an 80-20-type nickel-chromium alloy. Results obtained are compared with those reported earlier for nickel. In addition, tests were made on the alloy over a wider range of temperature, in order to assess the influence of temperature on the potency of the atmosphere effect.

Creep-rupture tests were made on sheet specimens at temperatures from 1100° to 1900°F. (593° to 1038°C.), in the stress range 1500 to 60,000 p.s.i. (0·7 to 26·8 tons per sq. in.). For a complete description of test equipment and procedure, reference is directed to the report on nickel (to be published in the Proceedings of a Conference on High-Temperature Materials, convened by the American Institute of Mining and Metallurgical Engineers in April 1957).

The results show that for Nichrome V, as for nickel, at high stresses and relatively low temperatures the properties are in general better in vacuo than in air: rupture life is longer and minimum creep rate is lower. At low stresses and higher temperatures the reverse is true. At the higher temperatures within the range used, this reversal takes place after a shorter time than at lower temperatures.

In long-time tests at high temperatures there was marked strengthening, accompanied by an increase in ductility.

The general features of atmosphere effect on Nichrome V are similar to those found for nickel, except that the points of reversal in strength of the vacuum and air specimens at high temperatures are displaced to longer times, an effect which is in accordance with the greater oxidation-resistance of the nickel-chromium alloy. The authors critically discuss the mechanism proposed in the earlier paper.

Materials for Supersonic Aircraft

H. B. SIPPLE and G. G. WALD: 'Materials and Processes for the Hot Airplane.'

Amer. Soc. Mechanical Engineers, Paper 57-SA-72, June 1957; 8 pp.

This paper is a general discussion of problems associated with the selection of structural and other materials for service under the stress and temperature conditions involved in supersonic flight. The data presented and the opinions expressed are based on research which, for some years, has been in progress by Lockheed Aircraft Corporation.

The opening section of the paper deals with some aspects of the temperature problems associated with aerodynamic heating. In discussing the rise of temperature related to increase in speed, a chart shows the range of temperatures which should be anticipated for various hypothetical types of aircraft over the next ten years. Further aspects of the temperature problem to which attention is given are the effect of time of exposure to high temperatures, and the rate at which the heat is produced.

From the structural point of view, the main question is the weight change involved in use of the materials which (consequent on the temperatures involved) must replace the aluminium-base alloys and steels employed in construction of more conventional aircraft. In this connexion some information is presented with regard to comparative total weight of aircraft constructed from the materials previously used and that of craft in which, for many essential

* *We shall be pleased to supply a free copy of this publication.*

parts, heat-resistant materials are used. Comparison of strength/weight ratios of materials which come into consideration for the new aircraft (constructional alloy steel, various types of stainless steel and titanium alloys) shows that much advantage is to be gained from the use of titanium and stainless-steel sheet, particularly the precipitation-hardenable varieties of the austenitic steels. Some of these materials are in relatively experimental stages of development, and in view of their promising properties the authors urge a concentrated effort to further their development to large-scale production. *Inter alia*, work is required also on the straight-chromium steels, and further research on nickel-base alloys is desirable, since such materials will be essential in certain high ranges of temperature. Establishment of the suitability of materials for production use for high-speed aircraft calls also for close investigation of production characteristics, fabrication methods, and reliability and reproducibility of properties. Particular attention should be devoted to the susceptibility of materials to brittleness and cracking under conditions parallel with those which will be encountered in service. (In this connexion values are given for tear-resistance of various materials and their susceptibility to crack propagation.) In the closing section of the paper brief consideration is given to non-metallic materials which must be employed in some of the functional systems of high-speed aircraft. The general temperature limitations for various non-metallic materials in common use for such purposes are indicated.

Emissivity of Inconel Alloys in Relation to Radiative Cooling of Hypersonic Aircraft

W. J. O'SULLIVAN and W. R. WADE: 'Theory and Apparatus for Measurement of Emissivity for Radiative Cooling of Hypersonic Aircraft, with Data for Inconel and Inconel X.'

Nat. Advisory Committee for Aeronautics Tech. Note 4121, Oct. 1957; 48 pp.

Cooling by radiation, alone or in combination with insulation or other cooling methods, is one of the most promising means of keeping within structurally tolerable limits the temperatures resulting from areodynamic heating of ultra-high-speed aircraft. Typical effects described in the report demonstrate that at the higher supersonic speeds radiation becomes a powerful means of cooling and that with increase in altitude the reduction of temperature produced by radiative cooling markedly increases. Since rate of loss of heat by radiation is directly proportional to the total hemispherical emissivity of the surface, practical interest lies in achieving maximum radiative cooling by development of surfaces having the highest possible value of total hemispherical emissivity.

A particularly attractive feature of radiative cooling is its simplicity and reliability, combined with low weight. Since emissivity is a property of the surface of a body, materials which are poor radiators, such as most metals and alloys, can be made good radiators by coating them with a thin layer of material of high emissivity. The possibility of practical application of these characteristics depends on the development of strongly adherent, stable and aerodynamically smooth coatings of high emissivity, capable of withstanding service involving high and fluctuating temperature conditions. The research reported in this publication was concerned with the possibility of applying emissive coatings on Inconel and Inconel X, two alloys which are of major importance in modern aircraft.

Since data available on the emissivity of surfaces are sparse, and, in many cases, not directly applicable to the cooling of aircraft, systematic investigation of the subject was instituted at the Pilotless Aircraft Research Division of the Langley Aeronautical Laboratory, under the auspices of the National Advisory Committee for Aeronautics. This report includes discussion of the theory underlying the investigation and the method of measurement of total hemispherical emissivity, a description of test apparatus, and a record of tests made on Inconel and Inconel X at temperatures up to 2000°F. (1093°C.)

It is shown that it is possible by heating in air, to produce on both materials, thin, smooth, adherent oxide coatings which do not flake off under rapid heating and cooling, are resistant to mild abrasion, emit diffusely and have stable emissive characteristics at temperatures up to 2000°F. (1093°C.). The total hemispherical emissivity of the coating on Inconel was found to vary from 0·69 at 600°F. (315°C.) to 0·82 at 1800°F. (982°C.), and for the coating on Inconel X values for the corresponding temperatures were 0·89 and 0·92. The results confirm the view that this method is promising for the cooling of ultra-high-speed aircraft.

Recent Progress in Production of Cast Components

See abstract on p. 47.

Niobium-Nickel and Other Niobium-base Alloys

C. T. SIMS, W. D. KLOPP and R. I. JAFFEE: 'Studies of the Oxidation and Contamination Resistance of Binary Niobium Alloys.'

Trans. Amer. Soc. Metals, 1957, vol. 51, *Preprint* 70; 34 pp.

Niobium is among the metals which are potentially useful in high-temperature engineering, but, like molybdenum, it oxidizes excessively when in contact with air at elevated temperatures.

Major effort with regard to molybdenum has until now been centred on formation of a chemically and thermally stable protective oxide film, since the most common oxide, MoO_3, is volatile at elevated temperatures. (In this connexion see, *inter alia*, papers abstracted in *Nickel Bulletin*, 1956, vol. 29, No. 3, pp. 45, 47.)

The possibility of improving the oxidation-resistance of niobium, is, however, considered more promising, since the oxide formed, Nb_2O_5, is relatively refractory, and it was anticipated that addition of appropriate alloying elements would lower the oxidation rate

by formation of a complex oxide such as a niobate or a spinel. This paper reports a series of experiments to determine the usefulness of alloying with fourteen other elements, to form binary alloys of types containing—

up to 35 at. per cent. of titanium, chromium or zirconium;

up to 25 at. per cent. of vanadium, molybdenum, tantalum or tungsten;

up to 5 at. per cent. of beryllium, boron, cobalt, iron, manganese, nickel or silicon.

Oxidation tests were made, in air, at 600°, 800° and 1000°C., and the rate of contamination (diffusion of oxygen into the metal) was studied, at the same temperatures, on niobium and on the alloys which proved most resistant to oxidation. (Results of oxidation tests on pure niobium had already been reported (*Battelle Memorial Institute Report* 1170, Jan. 1957).

The four elements which improved the oxidation-resistance of niobium were: titanium, vanadium, molybdenum and chromium. At 1000°C. optimum oxidation-resistance was obtained with 25% titanium, 10% vanadium, 5% molybdenum or 15% chromium. Titanium was the most effective oxidation-deterrent: in the range 600°-1000°C. the niobium alloy containing 25% titanium oxidized at a rate only 1/10-1/20 of that characteristic of niobium metal.

Zirconium, titanium, chromium and vanadium were the addition elements most effective in reducing oxygen diffusion (contamination).

Precipitation-Hardening Nickel-Chromium Stainless Steels

A. C. GILBRAITH: 'Precipitation-Hardening Stainless Steels. Heat-Treatment and New Materials in the U.S. Aircraft Industry.'

Metal Treatment and Drop Forging, 1957, vol. 24, Oct., pp. 395-9.

The author recapitulates some of the major problems confronting the design engineer in the search for constructional materials capable of withstanding the conditions encountered in supersonic flight. It is already recognized that for this purpose the precipitation-hardenable nickel-chromium stainless steels offer a peculiarly favourable combination of properties, and this article deals with three steels typical of the hardenable grades (Armco 17-7 P.H., Armco 17-4 P.H. and Allegheny A.M. 350). Details are given of the thermal treatments applied to these steels and of the properties obtainable by the respective treatments. (Some account of treatment and properties was contained also in a paper relating primarily to welding practice for the precipitation-hardenable grades of steel: see *Welding Jnl.*, 1957, vol. 36, Jan., pp. 9-27; *Nickel Bulletin*, 1957, vol. 30, No. 4, p. 60).

The heat-treatments used and the designations applied to the steels in the various conditions so produced are summarized in Table I (pp. 52-3); Table II p. 53 shows mechanical properties typical of 17-7 P.H. and 17-4 P.H. The metallurgical structures of the steels in the respective conditions are discussed in relation to the properties shown in the table.

Table I
17-7 P.H. Steel

Condition	Produced by
A	Annealed condition, resulting from heating at 1950°F. (1065°C.); air-cooling.
T	Heating, from condition 'A', at 1400°F. (760°C.) for 1½ hours; air-cooling (*or* water-quenching, provided that a temperature of 60°F. is reached in 1 hour).
TH-1050*	Heating, from condition 'T', at 1050°F. (565°C.) for 1½ hours; air-cooling.
TH-950	Heating, from condition 'T', at 950°F. (510°C.) for ½ hour; air-cooling.
RH-950	(1) Heating, from condition 'A', at 1750°F. (955°C.) for 10 mins.; air-cooling. (2) Freezing at −100°F. (−73°C.) for 8 hours. (3) Heating at 950°F. (510°C.) for 1 hour; air-cooling.
CH-900†	Heating, in the cold-rolled ('C') condition, at 900°F. (482°C.) in air or a reducing atmosphere for 1 hour; air-cooling, in 1 hour.

* By similar treatment, but at 1000°F. (540°C.) condition TH-1000 is obtained. It is noted that as the temperature of treatment is raised, the soaking time is lengthened.

† Condition giving maximum strength.

It is noted that where scaling of 17-7 P.H. occurs during any of the thermal treatments recommended the surface condition can be restored by pickling for 1 hour in a solution containing 10 wt.% NaOH + 3 wt.% K_2MnO_4, using the solution at 160°-180°F. (70°-82°C.), followed by 2-3 minutes dip in a solution consisting of 2 wt.% of HF and 10 wt.% of HNO_3, used at 110°-140°F. (45°-60°C.).

17-4 P.H. Steel

Condition	Produced by
A	Annealed condition, resulting from heating at 1875°-1925°F. (1020°-1050°C.); air-cooling or oil-quenching.
H-1075 or H-1150	Heating, from condition 'A', at 1075°F. (580°C.) or 1150°F. (620°C.). air-cooling.
H-875*	Heating, from condition 'A', at 875°F. (470°C.) for 1-4 hours; air-cooling.
TH-900†	Heating from condition 'A', at 900°F. (480°C.) for 1 hour; air-cooling.

* By similar treatment at 1000°F. (540°C.) condition TH-1000 is produced.

† Condition meeting most requirments.

The slight discolouration produced on tempering may be removed by pickling in a mixed HNO_3–HF solution at 110°-140°F. (45°-60°C.).

Table I

(*contd. from p. 52*)

A.M. 350 Steel

Sub-Zero Treatment

(1) Annealing at 1700°-1750°F. (925°-955°C.); air-cooling. (Condition L-1750.)
(2) Freezing, from condition L-1750, at −100°F. (−73°C.) for 2-3 hours; air-cooling.
(3) Heating at 650°-750°F. (345°-400°C.)*. *or* at 850°-950°F. (455°-510°C.)†.

* Condition of optimum corrosion-resistance.
† Condition of greatest ductility.

Double-Ageing Treatment

(1) Annealing at 1900°F. (1035°C.); air-cooling. (Condition H-1900.)
(2) Heating, from condition H-1900, at 1375°F. (745°C.) for 2 hours; air-cooling.
(3) Heating at 850°F. (455°C.) for 2 hours; air-cooling.

The slight discolouration observed after heating may be removed by dipping in a solution containing 15% HNO_3 and 2% HF, at a temperature of about 140°F. (60°C.).

Intermittent Stressing and Heating Tests

J. SALVAGGI: 'Intermittent Stressing and Heating Tests of Aircraft Structural Metals.'

Wright Air Development Center Tech. Report 53-24, *Pt.* IV, May 1957; 68 pp.

The considerable amount of creep-rupture data on high-temperature alloys already accumulated has, for the most part, been obtained under the idealized conditions of constant temperature and constant load, and some uncertainty exists as to the applicability of these values to the design of structures which, in service, will encounter intermittent-load and fluctuating-temperature conditions. Recognizing this limitation, a research programme was initiated, at Wright Air Development Center, to provide for comparative study of the creep-rupture behaviour of some typical aircraft materials subjected (1) to constant-temperature, constant-load conditions, (2) to constant-temperature intermittent-load and constant-load intermittent-temperature conditions, and (3) to a combined cycling of load and temperature. Parts I, II and III of Report 53-24 covered, respectively, test epquiment and technique, and tests made under conditions (1) and (2) mentioned above. This final report deals with the effect of combined temperature and load fluctuation.

In the course of the whole investigation various alloys have been studied, all in sheet form, and, on the basis of behaviour in the earlier tests, five materials were selected for evaluation in the complex combined-cycle tests: titanium alloy containing 7·7 per cent. manganese (C110M), high-purity titanium (A-70), titanium-stabilized 18-8 chromium-nickel steel, N-155 alloy (complex iron-nickel-chromium-cobalt-base alloy containing molybdenum, tungsten and niobium), and low-alloy chromium steel (S.A.E. 4130 type).

The results of this series of tests showed close similarity with those reported for the earlier intermittent-load and the intermittent-heat series. Creep and rupture were found to be accelerated, retarded, or unaffected according to the inherent properties of the respective materials, the temperature of test, and the time range under consideration. A condensed comparison of the response of the individual materials to (*a*) constant temperature and constant load, and (*b*) combined intermittent temperature and fluctuating load is given in the table on p. 54.

Table II

Mechanical Properties of 17-4 P.H. and 17-7 P.H. Steels in Various Conditions

(*see abstract on p. 52*)

	17-4 P.H.		17-7 P.H.			
	Condition 'A'	Condition 'H-900'	Condition 'A'	Condition 'TH-1050'	Condition 'RH-950'	Condition 'CH-900'
Yield Strength— p.s.i. t.s.i.*	110,000 (49·5)	178,000 (80)	40,000 (18)	185,000 (83)	220,000 (98)	260,000 (116)
Ultimate Strength—p.s.i. t.s.i.*	150,000 (67)	200,000 (89)	130,000 (58)	200,000 (89)	235,000 (105)	265,000 (118)
Elongation—% in 2 in. . .	6-15	12	35·0	9·0	6·0	2·0
Reduction of area, % . .	30-60	48	—	—	—	—
Modulus of Elasticity in tension—p.s.i. × 10^6	—	28·5	—	—	29·0	—
Hardness, Brinell.	341	420	—	—	—	—
,, Rockwell . .	C38	C44	B85	C43	C48	C47
Izod Impact, ft.-lb. . .	—	20	—	—	—	—

* To the nearest ½ ton

Table I

Summary of Effect of Combined Intermittent Temperature and Load *vs.* Constant Temperature and Load, on the Creep-Rupture Properties of Aircraft Structural Alloys

(*see abstract on p. 53*)

Alloy	Temperature		Deformation	Rupture	Deformation	Rupture
	°F.	°C.				
Titanium Alloy C-110M	800	427	No effect	Delayed	Markedly delayed	Delayed
Titanium A-70	700	370	No effect	No effect	Slight acceleration	Slight acceleration
	800	427	Slight delay	Slight delay	Slight delay	Slight delay
Type 321 Stainless Steel	1200	648	Slight delay	Accelerated	Accelerated	Accelerated
	1350	732	,, ,,	,,	,,	,,
N-155 Alloy	1350	732	Slight delay	Accelerated	Slight delay	Accelerated
	1500	815	,, ,,	,,	No effect	,,
4130 Steel	1000	538	Accelerated for short times Slight delay at long times	Slight delay	Accelerated for short times Slight delay at long times	Slight delay

Corrosion by Residual Fuel Ash: Use of Additives

W. E. YOUNG and A. E. HERSHEY: 'A Thermochemical Study of Some Additives to Reduce Fuel-Ash Corrosion.'

Corrosion, 1957, vol. 13, Nov., pp. 725t-32t.

The use of low-grade residual fuels for industrial gas turbines, necessitated by economic considerations, involves the well-known problem of corrosion by the products of combustion, mainly vanadium pentoxide and/or sodium sulphate. Removal of the sodium or vanadium from the fuel would be an expensive and difficult process and since, as the authors indicate by reference to the literature, attempts to develop metallic materials which will be resistant to this type of corrosion have, up till now, been relatively unsuccessful, attention has been directed to the possibility of rendering the products of combustion innocuous by the use of additives in the fuel.

It has been established that the 'catastrophic attack' caused by sodium and vanadium compounds is nearly always associated with the presence of a liquid-ash phase which fluxes off the protective oxide film normally present on refractory alloys. An endeavour has therefore been made to raise the melting point of the fuel ash by means of additives, so that at the service temperature of the turbine the ash will not be in a condition to cause sloughing of the protective film. To this end the authors studied the phase diagrams of binary mixtures of vanadium pentoxide and sodium sulphate with the following additives: magnesium sulphate, aluminium oxide, silicon oxide, calcium oxide and calcium sulphate. The study included investigation of the thermal stability of the respective substances.

From the results it is tentatively concluded that oxides of calcium, magnesium and aluminium should be effective if they could be preserved in the oxide form. The sulphate compounds would, however, usually be in the stable form, particularly at the temperatures of operation of gas turbines, and they would therefore not be effective: they could, in some conditions, be deposit-forming. On balance, and considering all the conditions involved in operation, the authors are of the opinion that aluminium compounds would be the most promising additive. Aluminium sulphate, even if initially formed, dissociates almost entirely to the oxide, at 800°C. for atmospheric conditions, and at 920°C. at 5 atmospheres.

Some of the conclusions drawn have been verified by full-scale tests in turbines, but additional laboratory and service tests are necessary to confirm their validity.

Discussion

In reply to a question with regard to the possibility of using precious-metal coatings on turbine parts in contact with fuel ash, it was stated that such a method held promise from the technical standpoint and might prove economically feasible.

A further question elicited information on preferential attack by oil-fuel ash on the cobalt constituent in Stellite alloys, as compared with more general attack on alloys of the nickel-chromium-iron (Inconel) and 25-20 chromium-nickel-steel types.

Effect of Trace Elements on Scaling of Electrical-Resistance Alloys

H. PFEIFFER: 'The Influence of Trace Elements on the Scaling-Resistance of Heat-Resistant Alloys.'
Werkstoffe und Korrosion, 1957, vol. 8, Oct., pp. 574-9.

The two main classes of electrical-resistance alloys (nickel-chromium- and aluminium-chromium-iron-base) normally contain trace amounts of other elements, introduced, for example, as deoxidizers or to increase the service life of the alloys. As a result of research, the significance of these minor additions has been well recognized for many years and the advantages of calcium, cerium and other elements are generally utilized in the commercial grades of such alloys.

This paper reviews, by reference to the literature and to the author's own experience, the position of theoretical and practical knowledge with regard to the effect of trace elements on scaling-resistance of high-temperature alloys, particularly those working under conditions involving fluctuations of temperature. Further evidence is added to support the theory that the beneficial influence of calcium and cerium consists in the more tightly adherent protective oxide film which is formed on alloys containing traces of these addition elements. The experimental data presented relate to aluminium-chromium-iron alloys containing rare-earth elements, and to nickel-chromium-iron alloys containing aluminium.

Reaction between Fused Sodium Hydroxide and Nickel-containing Materials

Work recorded in the previous literature has demonstrated that nickel is relatively resistant to corrosion by fused sodium hydroxide, even at elevated temperatures, provided that hydrogen is not removed from the field of reaction and that conditions are not such as to cause metal transport. For many applications, however, the mechanical strength of nickel at high temperatures is inadequate and it is necessary to alloy with other elements. Some of the metals which could be considered for this purpose are liable to react with sodium-hydroxide melts and the alloys formed with nickel are subject to corrosion by selective leaching of the reactive constituents. The reports abstracted here form part of a series covering studies of corrosion and mass transfer, in sodium-hydroxide melts, of nickel-containing alloys of widely varying types.

A paper by SMITH, STEIDLITZ and HOFFMAN served as an introduction to the series, describing the techniques used to study reactions occurring up to 815°C. (see *Corrosion*, 1957, vol. 13, Sept., pp. 561t-4t; *Nickel Bulletin*, 1957, vol. 30, No. 12, p. 231).

G. P. SMITH and E. E. HOFFMAN: 'The Action of Sodium Hydroxide Melts on Alloys of Nickel, Molybdenum and Iron at 815°C.'
U.S. Atomic Energy Commission Publn. ORNL-2131, Nov. 7, 1956; 7 pp.
See also *Corrosion*, 1957, vol. 13, Oct., pp. 627t-30t.

A study was made of the action of fused sodium hydroxide on nickel, iron, and the following types of nickel-base alloy:

Nickel-molybdenum, containing 10, 15, 20 and 25, per cent. molybdenum.
Nickel-iron, containing 20 and 33 per cent. iron.
Nickel-molybdenum-iron (80-10-10, 70-15-15, 60-20-20, per cent. types).

Samples were exposed for 100 hours at 815°C., and were subsequently weighed and subjected to metallographic examination. The method of test was the 'capsule' technique described in the introductory report.

A series of photomicrographs illustrates the condition of the specimens after test. The nickel specimens were slightly etched in appearance, but showed no signs of localized attack, and loss in weight was negligible. Iron had corroded significantly. Weight loss of the alloy specimens was only slight.

A characteristic feature of the corrosion process was the formation of pores near the surface of the alloy specimens. The form and location of the pores is discussed in relation to the crystal structure of the specimens. In most cases porosity occurred in the form of elongated pits, which frequently followed tortuous paths and intersected to form a maze of sub-surface channels. Measurements of depth of porosity indicated that alloys of nickel, iron and molybdenum having a nickel content of at least 70 per cent. are significantly more resistant to sodium hydroxide at the test temperature used than any other alloys previously tested. The corrosion mechanism involved selective leaching of iron and molybdenum from solid solution with nickel, and the degree of corrosion attack became less as the nickel content was increased.

G. P. SMITH, E. E. STEIDLITZ and E. E. HOFFMAN: Two-Phase Product Formed in the Reaction between Fused Sodium Hydroxide and Inconel.'
U.S. Atomic Energy Commission Publn. ORNL-2129 Apr. 4, 1957; 15 pp.
See also *Corrosion*, 1958, vol. 14, Jan., pp. 47t-52t.

Reaction between fused sodium hydroxide and Inconel was investigated by means of the 'controlled-atmosphere' procedure. Tests were made at temperatures in the range of 450°-800°C. and for times up to 400 hours, under blanketing atmospheres of purified hydrogen and purified helium. In addition, 'capsule' tests were conducted at 815°C. on specimens which had been stressed by cold-rolling.

The Inconel used for most of the tests was of commercial grade (nominal composition nickel 78, chromium 15, iron 7, per cent.), but representative tests were made on an alloy vacuum-melted and cast from virgin metals. This alloy did not differ

to any extent in corrosion reactions from the commercial material.

Corrosion rates were determined, and the microstructure of the products of corrosion formed on the specimens is discussed in extenso, with photomicrographs. The primary manifestation of the reaction was the formation of a corrosion layer consisting of a metallic phase (nickel containing a small amount of iron and chromium in solid solution) and a non-metallic phase comprising oxides and sodium oxysalts of chromium and iron, with possibly a very small amount of nickel ion. The metallic phase corresponded to chemical compounds resulting from the Inconel/sodium-hydroxide reaction, the former to that portion of the Inconel which did not react. The reaction therefore consisted mainly in selective leaching of iron and chromium from solid solution. The nature of the progressive attack occurring in various atmospheres is discussed.

G. P. SMITH and E. E. HOFFMAN: 'Corrosion Products formed in the Reaction between Fused Sodium Hydroxide and Iron-rich Alloys of Iron, Chromium and Nickel.'

U.S. Atomic Energy Commission Publn. ORNL-2156, May 14, 1957; 8 pp.

The report is devoted to discussion of corrosion-product layers formed by the action of fused sodium hydroxide on 18-8 and 18-8-Nb chromium-nickel stainless steels and on four iron-base alloys with nominal percentage compositions of: iron 80, chromium 20; iron 80, chromium 10, nickel 10; iron 74, chromium 18, nickel 8 (within the specification limits of Type 304L stainless steel); and iron 60, chromium 20, nickel 20, per cent.

The tests were run at 815°C. for 100 hours, using the 'capsule' technique. Photomicrographs of the corrosion layer on the 74-18-8 alloy are presented as typical.

The corrosion-product layers described in this report consisted of networks of non-metallic substances threading through metallic matrices. These layers somewhat resembled the corrosion product layers formed on Inconel by reaction with fused sodium hydroxide (see previous report), and it is reasonable to suppose that the two-phase corrosion products found on iron-rich alloys of iron, chromium and nickel were also formed by a selective leaching process. In all the tests reported except those involving the 80-10-10 and 60-20-20 iron-chromium-nickel alloys, solidified droplets of metallic sodium were observed on the inner walls of the capsules. The presence of metallic sodium is regarded as indicating the strong reducing action exerted by the alloys on sodium hydroxide at 815°C. During the experiments a substantial pressure of gaseous sodium was in contact with the melt and the latter contained considerable unconsumed hydroxide after completion of the experiments. The results therefore raise questions concerning the kinetics of sodium-ion reaction, since they conflict with previous reports that significant amounts of sodium were generated only after reduction of hydroxyl ions had ceased.

Ageing Treatment for Iron-Nickel-Chromium-base Alloys

T. W. EICHELBERGER: 'Effect of Ageing Cycle on the Properties of an Iron-base Alloy Hardened with Titanium.'

Trans. Amer. Soc. Metals, 1957, vol. 50, *Preprint* 21; 34 pp.

During the past few years much research has been carried out to determine to what extent it is possible to improve the properties of precipitation-hardenable high-temperature alloys by modification of the solution and/or ageing stages of the heat-treatment cycle. (See, for example, paper abstracted in *Nickel Bulletin*, 1957, vol. 30, No. 7-8, p. 129.) The present paper describes experiments on alloys within the following limits of composition: nickel 24·8-26·4, chromium 13·7-14·5, molybdenum 1·17-1·60, carbon 0·02-0·038, silicon 0·71-0·88, aluminium 0·06-0·19, or 0·068-0·078, titanium 1·48-2·63, per cent., iron balance. (The variations in titanium were specifically designed to demonstrate the influence of that element on response to heat-treatment.)

As an introduction to the report of the experimental work, a brief review is made of the ageing cycles commonly used in commercial heat-treatment: (1) ageing, for a given time, at a single temperature selected to give substantial hardening in a reasonable period; (2) double-ageing, involving treatment first at a relatively high ageing temperature and subsequently at a lower one, and (3) reversed ageing, in which the initial treatment is at a lower, and the second treatment at a higher, temperature. The author discusses the effects producible by the respective treatments, and the factors affecting the mechanism of the age-hardening process, in particular the effect of temperature and concentration of solute on the rate of nucleation of the precipitated phase. In the light of these considerations, and of the mode of fracture in creep characteristic of specimens hardened by the respective treatment, an attempt was made to develop an ageing treatment which would give improved creep-rupture properties in alloys of the type referred to above. Evaluation was by means of creep-rupture tests, on smooth and notched-bar specimens, at 1200°F. (649°C.). Tensile tests were made at room temperature and at 1200°F. (649°C.).

Preliminary experiments on specimens solution-treated at 1950°F. (1065°C.) and aged in varying cycles at 1200°F. (649°C.) and 1300°F. (705°C.) led to tests in which the effects of three experimental treatments were compared with those resulting from a treatment typical of the ageing cycles now industrially employed. Details of the respective treatments are shown below.

(1) 4 hours at 1200°F. (649°C.)
Temperature raised to 1300°F. (705°C.) in 2 hours; held at that temperature for 20 hours.
Air-cooled.

(2) 8 hours at 1200°F. (649°C.).
Temperature raised to 1300°F. (705°C.) in 8 hours; held at that temperature for 20 hours.
Air-cooled.

(3) 16 hours at 1200°F. (649°C.).
Temperature raised to 1300°F. (705°C.) in 16 hours; held at that temperature for 12 hours.
Air-cooled.

(4)* 20 hours at 1300°F. (705°C.).
Cooled to 1200°F. (649°C.) in 4 hours; held at that temperature for 20 hours. Air-cooled.

* Typical standard treatment

The results show that tensile properties both at room temperature and at 1200°F. (649°C.) are not affected by the variation of ageing treatment within the conditions used. The creep-rupture properties are, however, much affected by the ageing cycle. A long-time treatment (400 hours) at 1200°F. (649°C.) produces excellent creep-rupture properties, but this length of treatment must be discounted as uneconomic in large-scale production. Equally good results can, however, be obtained by the modified treatments described, to which the generic designation '*genuage treatment*'† has been given. The recommended cycle involves the following stages:

(1) Starting the ageing reaction at a temperature sufficiently low to give rapid general nucleation and a minimum of diffusion of the hardener content to nuclei in the grain boundaries.

(2) Slowly raising the temperature, to prevent retrogression, to a higher temperature at which the precipitated particles will grow more rapidly, i.e., 'acceleration' of growth.

(3) Holding at the higher temperature until the desired hardness is obtained.

(If desired, the material may then be given a stabilizing ageing treatment at a lower temperature, but for most applications this further treatment is probably unnecessary.)

In the work described, the upper and lower temperatures were, respectively, 1300° and 1200°F. (705° and 649°C.), but it is emphasized that these are not necessarily the optimum temperatures for all applications of the alloys considered.

It is believed that the same lines of approach and similar principles may profitably be explored with regard to ageing cycles for other precipitation-hardening alloys.

Production of Ni-Resist Austenitic Cast Iron

See abstract on p. 47.

Ni-Resist for Diesel-Engine Manifolds

See abstract on p. 48.

Microstructures of Cast Metals: Handbook

See abstract on p. 37.

† Derived from the phrase GEneral NUcleation Accelerated Growth

High-Temperature Properties of Steels for Steam Plant

A. I. SMITH, E. A. JENKINSON, D. J. ARMSTRONG and M. F. DAY: 'Creep, Stress-Relaxation and Metallurgical Properties of Steels for Steam-Power Plant Operating with Steam Temperatures above 950°F. (510°C.).'

Instn. Mechanical Engineers, Advance Copy, 1957; 24 pp.

Improvements in the design and efficiency of electricity-generating plant have resulted in a call for steels capable of operating at temperatures of the order of 1050°F. (565°C.), with pressures as high as 1,500 p.s.i. For such conditions the carbon steels and ½ per cent. molybdenum steels previously used are inadequate. Data on the higher-alloy steels which can be considered for this purpose are, however, insufficient as a basis for design, and further information is required to permit utilization of the properties of these steels to full advantage.

The Electrical Research Association has therefore sponsored investigations to provide such data, and this paper reports results of long-term tests made, under this sponsorship, at the National Physical Laboratory.

The steels investigated were of the following types:

Bolt steels ..	Molybdenum-vanadium Chromium-molybdenum-vanadium Chromium-molybdenum
Pipe steels.. ..	Molybdenum-vanadium 2¼ per cent. chromium-molybdenum Chromium-nickel-niobium (18-12-1)
Tube steels ..	2¼ per cent. chromium-molybdenum Chromium-nickel-niobium (18-12-1)
Castings (casings and steam chests)	Molybdenum-vanadium

Much detailed information is given on methods of manufacture of the steels examined, their composition, heat-treatments applied, and the mechanical properties of the samples included in the survey. All the steels were metallurgically examined in their initial conditions, and changes of microstructure and constitution occurring during prolonged testing at high temperatures were studied. Oxidation of the ferritic steels at high temperatures was also investigated.

The authors present a wealth of experimental data on the creep behaviour of the steels, and the results

of relaxation tests are given. The data are summarized in tabular and graphical form, and structural changes in the steels are illustrated by an extensive series of photomicrographs.

A balanced consideration of all the observations made leads to the following conclusions:

'With regard to the three bolt steels, the relaxation properties indicate that while the molybdenum-vanadium and chromium-molybdenum-vanadium types may just be adequate for plant using 1050°F. (565°C.), it is clear that any advance in steam temperatures would require the adoption of new bolt steels.

'Long-time creep and rupture tests on molybdenum-vanadium pipe steel have revealed its relatively high resistance to creep, but the steel has a tendency to rupture with moderately low ductility and intercrystalline fractures. Similar tests on tube and pipe steels of the 2¼ per cent. chromium-molybdenum type showed that this steel had somewhat lower creep-resistance, but the fractures were transcrystalline and the rupture ductility was higher than for the molybdenum-vanadium steel. The molybdenum-vanadium steel was structurally very stable, whereas molybdenum depletion of the matrix was revealed in the 2¼ per cent. chromium-molybdenum steel, a feature which may have contributed to its higher rupture ductility. Long-time creep and rupture tests on the austenitic 18-12-1 chromium-nickel-niobium pipe and tube steels have shown the high creep-resistance of this material, although it may not be possible to take full advantage of this because of a tendency to rupture with low ductility at high stresses and temperatures. Some suggestions are made for overcoming this problem. The long-time creep properties of a molybdenum-vanadium steel have shown that this steel offers a useful improvement over cast ½ per cent. molybdenum steel, although the former had creep-resistance considerably lower than that of the pipe steel of the same nominal alloy content. It is clear that for steam temperatures in excess of 1050°F. (565°C.), cast steels will be required which have creep properties superior to those of the molybdenum-vanadium casting tested. Several more advanced cast steels are already under test.'

See also

W. H. BAILEY, M. G. GEMMILL, H. W. KIRKBY, J. D. MURRAY, E. A. JENKINSON and A. I. SMITH: 'Creep Properties of Austenitic Nickel-Chromium Steels containing Niobium.'

Instn. Mechanical Engineers, Advance Copy, 1957; 9 pp.

This paper is supplementary to the preceding one, in that the information presented was obtained as a result of research sponsored by the same authority, to determine whether the creep properties shown by the heats of 18-12-1 chromium-nickel-niobium steel used in the earlier tests would regularly be reproduced in other steels made to the same specification.

Three steelmakers collaborated to collect laboratory test data on steels of this type, obtained by them over a considerable number of years, and the information was analysed to provide an estimate of the level of properties which may be regularly expected. It is believed that the bulk of the long-time data from British sources has been considered for this report. The information relates to sixteen heats of steel, three of which are those referred to in the preceding abstract. The tests, with the exception of those of the tube and pipe steels referred to in the companion paper, were made by the respective manufacturers. They relate to wrought bars of small diameter (⅝-in. to 1-in.) and to one rotor forging.

The chromium contents of the steels examined were fairly uniform but nickel varied from 9·5 to 14·5 per cent. This variation, however, appeared to have little effect on the creep-resistance, except in the case of the steel with 9·5 per cent. nickel, which at high temperature was rather weaker than the others. The carbon content ranged from 0·06 to 0·16 per cent. and the niobium was 0·89 and 1·91 per cent.

The tests by the manufacturers were carried out on wrought bars and, in one case, on a rotor forging. On a rupture basis they extended up to 8,000 hours at 550°C., 42,000 hours at 600°C., 41,000 hours at 650°C., 26,000 hours at 700°C., and 20,000 hours at 750°C. On the basis of 1 per cent. plastic strain the range was to 32,000 hours at 600°C., 30,000 hours at 650°C., 12,000 hours at 700°C. and 14,000 hours at 750°C. Since the tests were made by different manufacturers, for different purposes, there was no uniformity in the testing conditions.

Considerable differences were found between the creep-resistances of the various steels, and the authors are fully satisfied that these differences are real, i.e., not attributable to variation in test procedure in the collaborating laboratories. It is considered that the following data, for two steels tested at 700°C., give a fair but not exaggerated impression of the differences which can exist in steels of nominally identical type.

	Stress for 1 per cent. strain in 10,000 hours, t.s.i.	Stress for rupture in 10,000 hours, t.s.i.
Steel 1 ..	2·1	3·1
Steel 2 ..	2·6	4·7

Although the figures quoted are for 10,000 hours, differences of the same order could be expected to exist at 100,000 hours.

Under prolonged stress the steels showed a certain susceptibility to fracture at low elongation. At 550°, 600° and 650°C. there was a definite trend towards lower elongation values with increase in testing time. This trend is reversed at 700° and 750°C. and it appears that the steels go through

a stage of maximum brittleness which is passed earlier in the test at higher temperatures. In some steels the minimum elongation was so high that there would be little danger of premature fracture in service: in others elongations as low as 2 or 3 per cent. were common.

The paper incorporates some recommendations on design stresses for use of these steels at temperatures of 550°–750°C. Comparison is made with stresses permissible under the terms of the A.S.M.E. Boiler Code.

Electrical Conductivity and Hall Constant of Nickel-Chromium Alloys

See abstract on p. 45.

Stress-Corrosion Cracking of Stainless Steel in Contact with Insulating Media

A. W. DANA: 'Stress-Corrosion Cracking of Insulated Austenitic Stainless Steel.'

A.S.T.M. Bull., 1957, No. 225, Oct., pp. 46–52.

The paper reports preliminary results of an investigation of stress-corrosion cracking in austenitic stainless-steel piping and tubing protected by thermal insulating material which had become wet. Analysis of the products of corrosion on the tube surface showed a chloride content of 3–5 per cent. (as compared with less than 0·5 per cent. present in the insulating material), and it was therefore postulated that the cracking was caused by concentration of water-soluble chlorides leached from the insulating material, e.g., by rainwater or by leaking steam.

A full account is given of tests made to confirm the accuracy of this assumption. The test conditions allowed for estimation of the influence of composition of the corrodent, temperature (60°, 80° and 100°C.), time of exposure, and stress.

Results derived from the tests at 100°C., together with data on the chloride content of the various insulating materials and the composition of the corrosion products, comprise the major portion of the paper. Photomicrographs illustrate the types of cracking produced in the respective conditions of test.

From the results it is concluded that the leaching reaction and the mechanism by which chlorides are concentrated at the surface of the equipment are of primary importance in determining the period which elapses before onset of cracking. It was found that water-soluble chlorides are present in all three types of thermal-insulation materials studied (85 per cent. magnesia, calcium silicate, and glass fibre). There was little difference in the chloride contents of the three materials.

With specimens tested at 100°C. the 85 per cent. magnesia insulator showed the greatest tendency to produce cracking. After 200 days' exposure, no statistical significant difference in crack-producing tendency was found between the calcium silicate and the glass fibre. Temperature of exposure has a pronounced influence on the incidence of stress-corrosion cracking of specimens in contact with moist insulating materials.

Corrosion of Metals in Marine Tropical Atmospheres

A. L. ALEXANDER, B. W. FORGESON, H. W. MUNDT, C. R. SOUTHWELL and L. J. THOMPSON: 'Corrosion of Metals in Tropical Environments. Part I. Test Methods used and Results obtained for Pure Metals and a Structural Steel.'

U.S. Naval Research Laboratory, Washington, Report NRL 4929, June 19, 1957; 44 pp. *P.B.* 121952.

In early 1940 plans for expansion of the Panama Canal by the construction of a third set of locks centred attention on selection of materials suitable for exposure in the tropical conditions prevailing in that area. In view of the magnitude and importance of the project, and the relative sparsity of information on corrosion in tropical atmospheres, a general corrosion investigation was initiated, under the auspices of the U.S. Navy, to ensure specification of materials which could reasonably be expected to give long and satisfactory service.

The research programme then planned included immersion of the selected metals in salt, brackish and fresh waters, for periods of one, three and five years. Postponement of the construction project, due to World War II, allowed of supplementing such tests by an additional series which provided for use of duplicate specimens, additional types of material, and bimetallic couples, and the extension of the exposure sites to include representative marine and inland atmospheres, freshwater immersion and continuous and mean-tide seawater exposure. The number of specimens placed on the test at the various stations allowed for removal, for examination, after one, two, four, eight and sixteen years. In all, some fifty metals and alloys were included. The eight-year specimens were removed in 1955, and this report deals with the examination of six selected materials (aluminium, lead, copper, zinc, nickel and structural steel), to the end of the eight-year period.

As a background to the report on the corrosion of the individual metals, a description is given of the test sites, pre-exposure processing of the specimens and their installation and inspection, the composition of the environments in which they were exposed, processing on removal after test, and methods used for evaluation of corrosion.

The condition of the six types of material discussed is illustrated by detailed tabular and photographic data. From the observations made, the following conclusions are drawn:

> 'Aluminium is quite resistant to corrosion in all environments studied, with the exception of fresh water. Pitting in fresh water is accelerated somewhat, perhaps by the higher temperature of the tropical water.
>
> 'Lead is quite resistant to corrosion but displays the rather unique property of increasing in tensile strength while undergoing a measurable reduction in thickness during seawater immersion.
>
> 'Copper, as measured by reduction in thickness, is appreciably corroded only in seawater.

'Zinc and nickel corrode in the tropics at rates which might be predicted from those measured at sites such as Kure Beach, N.C. However, the pitting of nickel in tropical seawater appears considerably greater than might be predicted from previously available data.

'Of considerable general interest, moreover, is the relation of corrosion rates of structural steel in the tropics to rates observed for similar alloys in temperate climates. For the steel studied, the following generalizations appear justified:

(*a*) For marine atmospheric exposure, the rate of corrosion of structural steel in the tropics is approximately double that at Kure Beach, N.C., but of the same general character.

(*b*) For inland atmospheric exposure the corrosion rate of structural steel is approximately double that in a typical U.S. industrial atmosphere.

(*c*) The rate of corrosion of structural steel in continuous seawater immersion is about the same in the tropics as on the middle Atlantic coast of the United States, with the exception that the initial rate in the tropics is slightly greater.

(*d*) Although the corrosion of steel in fresh water varies widely, the rate in the tropics is generally much greater than that in domestic waters.'

Resistance of Nickel, Monel and Inconel to Fluorine

M. J. STEINDLER and R. C. VOGEL: 'Corrosion of Materials in the Presence of Fluorine at Elevated Temperatures.'

Argonne Nat. Laby. Report ANL 5662, Jan. 1957; 21 pp.

This report describes work carried out to assist in selection of materials of construction for equipment employed in the Fluoride Volatility Process which is applied to irradiated plutonium-uranium alloys.

The process may include the following stages:

(1) Dissolution of the irradiated alloy in bromine trifluoride.

(2) Separation of the volatile fluorides and unreacted bromine trifluoride from the non-volatile fission product and plutonium fluorides by distillation.

(3) Fluorination of the non-volatile distillation residue at elevated temperatures, using elemental fluorine.

(4) Distillation of plutonium hexafluoride and subsequent purification and decontamination.

(5) Removal of fission-product wastes from the dissolver, using a suitable high-melting medium.

Although the temperature necessary for operation of the fluorination step has not been finally determined, preliminary evidence has indicated that temperatures in the region of 350°C. are of particular interest. It was expected that at these temperatures equipment would suffer corrosion, and one of the objects of the work undertaken at the Argonne Laboratory was to evaluate the magnitude of this problem. A temperature range of 400°–750°C. was covered, and the materials tested were nickel, Monel, Inconel, copper, calcium fluoride and alumina. Full details are given of the apparatus and procedure used.

Corrosion rates were calculated on a loss-of-weight basis and by determination of the thickness of the corrosion film. After exposure the specimens were subjected to metallographic examination: photomicrographs of the nickel and nickel-alloy specimens are included in the report. The comprehensive data obtained are shown in tabular form and the results for each material are briefly discussed.

On the basis of the results, the authors draw the following conclusions. At low temperatures (500°C.) nickel and Monel appear to exhibit good resistance to corrosion by fluorine. Copper, though not so satisfactory, has acceptable resistance for many applications. As the temperature is raised, Monel becomes less satisfactory, but nickel showed the lowest rate of corrosion among the materials tested.

Since the data in the literature on corrosion of materials in gaseous fluorine at elevated temperatures are in many cases contradictory, the authors tabulate, as an addendum to the report, the results of several of the most important investigations, and make a short summary of relevant details. The information confirms the specially high resistance of nickel and the fact that Monel is satisfactory at temperatures up to about 600°C. There appears to be some doubt with regard to the suitability of copper for such applications above 500°–600°C.

Corrosion by Acetic Acid

NAT. ASSOCN. CORROSION ENGINEERS: 'Corrosion by Acetic Acid.'

Corrosion, 1957, vol. 13, Nov., pp. 757t–66t; *N.A.C.E. Publn.* 57-25.

The N.A.C.E. Technical Practices Committee TA-3, which sponsors this report, was established 'to correlate information on corrosion problems involved in the manufacture, storage and transport of relatively pure acetic-acid solutions.' The report is based on information received from producers and users of the acid, and from firms supplying materials to be used in handling it, correlated with results of laboratory experiments and field tests.

The subject is dealt with under the classification of materials, in sections covering summaries of data available from various sources on the behaviour of aluminium and aluminium alloys; copper and copper alloys; stainless steels of medium and higher alloy content; cast irons; Monel, Inconel and nickel; nickel-molybdenum-base alloys; silver and lead; titanium, tantalum and zirconium; non-metallic materials. In each section consideration is given to types of corrosion to which the individual materials are peculiarly susceptible, as well as to their general resistance to attack. Discussion includes reference

to pitting and crevice corrosion, dezincification (of brass), stress cracking, intergranular corrosion, and galvanic attack.

Consideration of the available evidence leads to the following general recommendations on materials for handling and storage of acetic acid:

Ambient-temperature storage of refined glacial acetic acid	Tanks and tank cars Aluminium alloys Heating coils 18-8 Cr-Ni-Mo steel Piping 18-8 Cr-Ni-Mo steel Valve and pumps 18-8 Cr-Ni-Mo steel

The molybdenum-containing grade of nickel-chromium stainless steel is recommended for maintaining maximum purity of acid: where small amounts of turbidity colour pick-up can be tolerated a straight 18-8 chromium-nickel steel can be used.

Ambient-temperature storage of pure dilute (less than 90%) acetic-acid solutions	Tanks and tank cars 18-8 Cr-Ni Steel Piping 18-8 Cr-Ni steel Valves and pumps 18-8 Cr-Ni-Mo steel

For contact with contaminated acid or storage at elevated temperature the molybdenum-containing grade is preferred.

Choice of materials for acetic-acid process equipment is dependent, to a large extent, on the purity of the acid, temperature, and the nature of the environment (oxidizing or reducing). The austenitic stainless steels or copper and the copper-base alloys will satisfactorily meet most requirements. Nickel-molybdenum-base alloys of the Hastelloy B and C types, and the nickel-silicon-aluminium alloys of Hastelloy D and similar types are resistant to pure acetic-acid solutions at all normal concentrations and temperatures. Such materials are sometimes used where acetic acid is employed in conjunction with inorganic acids and salts which limit the usefulness of stainless steels or copper alloys. The nickel-molybdenum-iron and nickel - silicon - aluminium alloys are useful under reducing conditions, e.g., in handling mixtures of acetic and sulphuric acids. For acetic-acid-containing solutions which are oxidizing the chromium-containing Hastelloy C-type alloy is preferred.

Stainless-Steel Linings for Sulphite Digesters

J. M. JAPP: 'Comparative Study of Linings for Sulphite Digesters.'

Paper Trade Jnl., 1957, vol. 141, Sept. 30, pp. 28-33, 48.

This is an essentially practical paper, containing information and making recommendations based on the author's extensive experience in several plants and on communications received from representative paper-making firms in the U.S.A. and in European countries.

Supported by evidence thus accumulated, the relative advantages and disadvantages of the following types of sulphite-digester vessels are discussed: riveted or welded steel with ceramic-brick, carbon-brick, or stainless-steel linings, and stainless-steel-clad vessels. Typical service experience is reported for the respective forms of plant.

The evidence received indicates that while intermittently attached stainless-steel linings are superior to brick linings, vessels of the stainless-lined type will always require more frequent maintenance than a correctly designed stainless-clad vessel.

In Europe stainless-clad digesters have come rapidly into favour within the past few years, and unqualified approval is given by the firms in whose plants they are operating. Some of the advantage gained in ease and cleanliness of processing and quality of product are noted. In North American mills also, experience has in some cases been satisfactory, but maintenance difficulties have retarded general adoption of clad vessels.

The second part of the paper contains a discussion of some of the main factors which influence the service behaviour of stainless-clad digesters. Consideration is first given to the types of corrosion which may occur as a result of unsuitable processing in fabrication, unfavourable design of vessel, erosion by rapidly-flowing liquids, and stress corrosion induced by unduly severe mechanical working or warping during welding.

A balanced comparison is made of conditions obtaining in European and in North American mills, the types of wood handled, substances used in processing, type of steel employed for the cladding, and surface finish of the steel. As a result of the survey, the author makes comments and recommendations, the most important of which are summarized below:

Im the U.S.A. metallurgists generally have favoured the use of the extra-low-carbon stainless steels for the cladding, but this decision, based on resistance to corrosion in the Huey boiling-nitric-acid test, is considered unwise, since conditions obtaining in sulphite digesters differ radically from those of the test. The titanium-stabilized grade which has been adopted in Europe has proved definitely superior for this purpose and offers economic advantages. The following composition is considered suitable: chromium 17·5-19·5, nickel 12·5±, molybdenum 2·5-3·5, silicon 0·4, manganese 1·2, carbon 0·08, per cent., titanium 5 times the carbon content. (If no titanium is present, carbon should not be more than 0·03 per cent.)

There is strong evidence to support the recommendation that the cladding should have a polished surface. The author suggests that finishing with two operations of 60 and 80 grit, followed by slurry polishing, will give the smoothness necessary to inhibit scaling.

Major emphasis is laid on establishment of welding conditions which will not impair the corrosion-resistance of the cladding: weld design and welding procedure to be used in fabrication of a new digester in the author's plant are described and illustrated. A localized stress-relief treatment which can be

carried out without impairment of corrosion-resistance has been developed, and particulars are available on request.

In connexion with complaints of corrosion in the upper dome section of stainless-clad digesters, suggestions are made for slight modification in design which will facilitate rapid removal of vapour condensate and thus obviate corrosive attack.

Nickel-containing Materials in Photographic Processing Equipment

J. R. TURNER: 'Materials of Construction for Color Processing Equipment.'
P.S.A. Tech. Quarterly, 1956, Nov.
Reprinted from *Photographic Science and Technique*, *Ser.* II, 1956, vol. 3, Nov., pp. 137–44.

The author emphasizes the need for careful consideration of materials used in photographic processing equipment, reviews some of the factors affecting the choice, and discusses difficulties which have been encountered in the use of certain types of material. Examples are given of the application of some specialized properties of metals and alloys. It is pointed out that the major considerations affecting selection are (1) interaction between the processing solutions and the materials of construction, (2) balancing of economic factors against optimum results. Selection of materials is therefore discussed from two aspects: (*a*) the effect of materials of construction on the quality of the film or paper produced, and (*b*) the life and behaviour of constructional materials as influenced by the solutions in contact with them. As an introduction to discussion of these two aspects, the author draws attention to some effects which are detrimental to photographic quality and emphasizes the significance of correct design, in order to take full advantage of the materials selected.

The effects of processing solutions used at various stages are reviewed, and special consideration is given to factors which may detrimentally influence the corrosion-resistance of metallic materials in photographic applications, e.g., 'cleaning' of stainless steel equipment after passivation, and corrosion resulting from interaction between chemicals carried over from one stage of a process into the next.

Contamination of processing solutions directly attributable to contact with constructional materials is stated to occur mainly in the presence of either photographically active compounds of copper, tin or sulphur, or with organic compounds which affect the processing characteristics of films and prints. Methods of countering these effects and other deleterious contaminations are suggested.

The remainder of the paper is devoted to discussion of materials suitable for specific applications in photographic equipment. In each case examples are given of problems, peculiar to a component, which have been solved by selection of a suitable material. Particular mention is made of the advantages of stainless steel.

Attention is drawn to the need for materials which permit of easy fabrication, e.g., drums and processing reels may be made from stainless steel. The paper ends with a short survey of the various uses of plastic materials in this field.

An interesting feature of the paper is an appendix listing materials which have proved, in service, to be suitable for specific items of processing equipment. Molybdenum-containing nickel-chromium stainless steel is the preferred material for many of the components mentioned.

Nickel-Aluminium-Bronze Marine Propellers

See abstract on p. 46.

Electrode Processes during Corrosion

M. STERN: 'Fundamentals of Electrode Processes in Corrosion.'
Corrosion, 1957, vol. 13, Nov., pp. 775t–82t.

The majority of corrosion reactions in aqueous environments occur by an electrochemical mechanism, and selection of an appropriate material for a particular application requires an understanding of the fundamental processes involved. Recent advances in the theory of electrode kinetics provide a simple means by which experimental observations may be explained, and this paper was presented in 'an effort to bridge the gap between the thinking of the 'electrode kineticist' and the practising 'corrosion engineer' '.

The first part of the paper centres on theoretical consideration of the fundamental phenomena involved in the corrosion process, and the practical application of the basic principles so established is illustrated by examination of classic experiments on the corrosion of iron and steel. These comprised investigations into the effect, on the rate of corrosion, of pH, oxygen concentration, velocity of environment, composition and heat-treatment, and a study of galvanic corrosion resulting from coupling of dissimilar metals in a corrosive environment. The section on galvanic couples is devoted to consideration of data on the effect of seawater velocity on corrosion of steel coupled with 18-8 type chromium-nickel stainless steel, titanium, copper and nickel reported by H. R. COPSON (*Industrial and Engineering Chemistry*, 1952, vol. 44, Aug., pp. 1745–52).

Testing of Susceptibility to Intercrystalline Corrosion in Austenitic Steels

H. ZITTER: 'Study of Methods for Determining Susceptibility to Intercrystalline Corrosion in Austenitic Chromium-Nickel Steels.'
Archiv f.d. Eisenhüttenwesen, 1957, vol. 28, July, pp. 401–16.

The author criticises methods generally used for estimation of susceptibility to intercrystalline corrosion, on the ground that there is little evidence correlating results obtained by such tests with

behaviour in service conditions. (A review is made of methods which have been proposed by various investigators, and of conditions suggested for sensitizing of austenitic steels. Reference is directed to original literature.)

Experiments are reported in which welded and unwelded specimens of a steel containing carbon 0·07, chromium 18, nickel 8, per cent. were exposed to the Huey (boiling-nitric acid), the acidified copper-sulphate, and the hydrofluoric-acid/nitric-acid tests. Some tests were made also by the oxalic-acid-etch (screening) procedure. Particular attention was centred on the times of immersion needed to ensure discrimination by the respective procedures, and the temperature limits within which the steels must be sensitized to ensure that the respective tests give satisfactory indication of susceptibility to intercrystalline breakdown.

From the detailed experimental data reported it is concluded that the mixed-acid solution gives the most rapid response and reveals susceptibility for steels sensitized over the widest range of temperature. The copper-sulphate test was the most temperature-critical: the Huey test was between the two. The hydrofluoric/nitric solution is therefore recommended as most suitable for detection of susceptibility in welds, where time of heating may vary considerably according to welding conditions. The copper-sulphate test is considered to be best suited for testing of unwelded austenitic steel, care being taken that the sensitizing temperature is in the region of 650°C. and that, because of the sharpness of attack characteristic of this solution, time of exposure to it is not unduly prolonged.

Photometric Determination of Tungsten in Austenitic Nickel-Chromium Steels

L. A. MACHLAN and J. L. HAGUE: 'Photometric Determination of Tungsten in Steel and Titanium Alloys with Dithiol.'

Jnl. Research, Nat. Bur. Standards, 1957, vol. 59, Dec., pp. 415-20; *R.P.* 2812.

Tungsten is finding increasing use, in small percentages, as an alloying element in ferrous materials. Among its applications, high-temperature alloys of nickel- and cobalt-base types and the austenitic nickel-chromium steels are important, as are tool alloys in which tungsten is present.

Gravimetric methods of analysis are not well suited for determination of small amounts of tungsten. Iron and molybdenum retard the precipitation of small quantities of tungsten by the usual cinchonine procedure. Titanium, niobium, tin and tantalum are often encountered, and any procedure devised must provide for their presence. Of the reactions available for photometric determination of tungsten, the most commonly employed are those that use thiocyanate, hydroquinone, and dithiol as reagents. The first two procedures have limitations to which reference is made by the authors, whose work was designed to determine the conditions necessary to make the dithiol reaction specific for tungsten in the presence of other elements liable to be present in ferrous materials. The work was extended to provide for determination of tungsten in titanium.

The paper gives much detail on the apparatus and techniques used in the experiments, as a result of which the following method is recommended:

'The sample, 0·1-0·2 g. in weight, is dissolved in aqua regia, and a sulphuric-phosphoric-perchloric-acid mixture is added. The solution is evaporated to fumes of sulphuric acid and diluted to volume with diluted sulphuric acid (1+3). An aliquot portion of the solution is treated with dithiol in diluted sulphuric-acid solution (1+3) containing sulphur dioxide, and molybdenum and certain other potential interferants are removed by extraction with chloroform. Copper and other elements forming insoluble dithiolates are removed by filtration. The tungsten-dithiol complex is then formed, after the addition of hydrochloric acid, stannous chloride, and dithiol, and extracted with butyl acetate. The absorbancy of the tungsten complex is determined at approximately 635 μ. An accuracy of 0·005 per cent. of tungsten, or better, is indicated in the range 0·05 to 0·50 per cent. of tungsten, and of about 0·001 per cent. for amounts of less than 0·05 per cent. of tungsten.'

The accuracy of the method was tested on a wide range of synthetic materials and on National Bureau of Standards standard samples of various types of steel, including a range of complex austenitic nickel-chromium types.

Full details are given also of the modified procedure for estimation of small amounts of tungsten in titanium.

Determination of Niobium and Tantalum in Steel

BRIT. IRON AND STEEL RESEARCH ASSOCN., METHODS OF ANALYSIS COMMITTEE: 'An Investigation of a Method for Combined Determination of Niobium and Tantalum in Steel.'

Jnl. Iron and Steel Inst., 1957, vol. 187, Dec., pp. 341-3.

Details are given of a method the validity of which has been tested by study on a collaborative basis by several laboratories. The method is applicable to analysis of nickel-alloy steels. Work on the separate determination of the two elements is in progress; preliminary results were reported in a paper given at the 11th Chemists' Conference, October, 1957.

Determination of Cobalt in High-Nickel Alloys

M. ZIEGLER, O. GLEMSER and E. PREISLER: 'The Photometric Determination of Cobalt as Tributylammoniumhexarhodanocobaltate (II).'

Zeitsch f. analytische Chemie, 1957, vol. 158, Pt. 5, pp. 358-60.

Supplementing a paper published in *Angewandte Chemie*, 1956, vol. 68, p. 436, which described this method of estimating cobalt, the authors demonstrate its applicability to determination of the element in nickel-chromium-(iron) alloys and austenitic

nickel-chromium steels, glass, and zinc oxide. Typical results are quoted for analysis of National Bureau of Standards standard samples.

Etchant for Differentiation between Molybdenum-containing and Molybdenum-free Austenitic Steels

F. K. NAUMANN and W. CARIUS: 'Etching Procedure for Distinguishing between Corrosion-Resisting Chromium-Nickel and Chromium-Nickel-Molybdenum Steels.'

Archiv f.d. Eisenhüttenwesen, 1957, vol. 28, Oct., pp. 641–4.

The test described was developed to determine the composition of wires used in mesh material stated by the supplier to contain given numbers of wires made from molybdenum-containing steel, with the balance of a molybdenum-free type. (The supplier had guaranteed this proportioning of wires in the two types of steel on the basis of tests in a hot dilute aqueous solution of hydrochloric acid containing potassium ferrocyanide.)

Work carried out in developing the check test is described. The technique is based on the solubility of the steels in hydrochloric- or sulphuric-acid solutions, to which potassium ferrocyanide or potassium ferricyanide is added as indicator. (The method is based on the fact that the hexacyanoferrate ion $Fe(CN)_6^{4-}$ reacts with the Fe^{III} ion to give a deep blue colour.) Systematic variation of conditions of test (composition of solution, temperature of test and duration of immersion) led to selection of the following conditions as optimum:

	Parts
Conc. HCl (sp. gr. 1·19)	1
Water	1
Aqueous soln. of potassium ferrocyanide (30 g./L.)	1
Temperature of operation about 50°C.	
Etching time	3 mins.

Straight chromium-nickel steels subjected to this test take on a vivid green coloration; molybdenum-containing steel remains unchanged in colour. On exposure for a short time to air the green tone turns to a distinct blue, thus enhancing the distinction. If the etching period is unduly prolonged, a heavy dark deposit forms on the molybdenum-free steel, making differentiation of the two types somewhat difficult.

Identification Tests for Nickel Alloys

See abstract on p. 47.

Photoelectric Colorimetric Methods for Analysis of Steels

See abstract on p. 49.

Welding Handbook

See abstract on p. 38.

Hard Facing with High-Nickel Alloys

J. R. SMITH: 'Spraywelding: A Hard-Facing Preventive Maintenance Process.'

Iron and Steel Eng., 1957, vol. 34, Sept., pp. 90–4; disc., pp. 94–5.

The paper discusses the use of the Spraywelding process as a hard-facing procedure for initial protection of parts which will operate in abrasive and corrosive conditions, and for rebuilding of worn parts. Composition limits of the alloys used are given in the table below.

The Spraywelding process involves three basic operations:

(1) *Surface Preparation*

All traces of previous surface treatment, such as plating, should be removed, and if the surface hardness is higher than Rockwell C 30 annealing is essential. To maintain the same dimensions after as before spray treatment, the surface must be undercut to a depth governed by the thickness of overlay required (e.g., 0·015 in. per side for corrosion-resistance and 0·040 in. for resistance to abrasion). Grit-blasting is then necessary, to ensure a sound mechanical bond between the basis metal and the overlay.

(2) *Surface Spraying*

In Spraywelding the alloy powder is fed from a hopper through a carburettor, where it is picked up by an air jet and propelled through a hose to the gun. Here it is heated to its plastic range by an oxy-acetylene flame and blown onto the prepared surface. Details are given of the technique used and the thickness of the deposit required to allow for contraction during fusion.

(3) *Fusion of the Overlay*

The principle involved is to bring the overlay and the basis metal to the fusion temperature of the former, where the alloys wets and bonds to the basis metal. The cycle used by the Bethlehem Steel Company (on whose practice the article is based) is described as follows:

The parts are placed in a low-heat electric furnace,

Powders used in Spraywelding

	Nickel %	Chromium %	Boron %	Carbon + Silicon + Iron %
No. 4 powder	75-85	8-14	2-3	8 max.
No. 5 powder	71-81	10-17	2-4	9 max.
No. 6 powder	65-75	13-20	2·75-4·75	10 max.

in a reducing atmosphere, and the temperature is slowly raised from 1600°–1800°F. (870°–980°C.), i.e., to a temperature just below that at which the No. 6 alloy becomes plastic. After soaking, the parts are transferred to an electric furnace and brought up to the fusion temperature of 1900°F. (1040°C.). (The fusion temperatures for the Nos. 4 and 5 alloys are, respectively, 2025° and 1950°F. (1105° and 1066°C.)) At the fusion temperature the components are removed and either air- or furnace-cooled. Fusing can also be carried out by means of an oxy-acetylene torch or by induction heating.

Reference is made to tools suitable for machining and grinding the overlay, together with data on hardness of the facing alloys at temperatures up to 1500°F. (815°C.). Comparison is made of the corrosion-resistance of Alloy No. 6 with that of 18–8 chromium-nickel stainless steel.

Among the basis materials listed as suitable for processing are the A.I.S.I. 300 Series of stainless steels (with the exception of Type 303*), malleable iron, nickel, Monel, Inconel, Nichrome and most high-temperature alloys.

The paper ends with a review of the benefits derived from Spraywelding of sleeves, valves, shafts, pulleys and other parts subject to abrasion, combined in some cases, with corrosion attack.

Discussion which followed presentation of the paper centred on specific applications and the economics of the process.

* Free-cutting type containing higher sulphur, phosphorus or selenium.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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